**MODERNIZING A PREVENTIVE MAINTENANCE STRATEGY FOR FACILITY AND INFRASTRUCTURE MAINTENANCE**

THESIS

Ross E. Dotzlaf, Capt, USAF

AFIT/GEM/ENV/09-M03

**DEPARTMENT OF THE AIR FORCE**

**AIR UNIVERSITY**

**AIR FORCE INSTITUTE OF TECHNOLOGY**

Wright-Patterson Air Force Base, Ohio

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THESIS

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Ross E. Dotzlaf, B.S.

Captain, USAF

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Ross E. Dotzlaf, B.S.

Captain, USAF

Approved:

Alfred E. Thal, Jr. — 2 FEB 2009
Alfred E. Thal, Jr., PhD (Chairman) — date

3 Feb 09
Christopher J. West, LtCol, USAF (Member) — date

Walter Miller — 2 Feb 09
Walter L. Miller, Capt, USAF (Member) — date

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## Abstract

Preventive maintenance (PM) is defined as regularly scheduled maintenance actions based on average failure rates. A properly implemented PM strategy can provide many benefits to an organization in terms of extending equipment life, optimizing resource expenditures, and balancing work schedules. Periodic evaluation of a PM strategy can help identify ways to improve efficiencies and maximize effectiveness. This research effort was accomplished by performing a case study of the United States Air Force's infrastructure and facility PM program known as the Recurring Work Program (RWP).

The methodology consisted of two phases. The first phase, intended to develop an understanding of the gap between the current program and what it needs to become, consisted of two segments: data collection and a strengths, weaknesses, opportunities, and threats (SWOT) analysis. Data was collected during 25 interviews with a wide variety of Air Force members highly experienced with the RWP. Using the interview data, the SWOT analysis compared the state of the current program to relevant maintenance management theory and best practices from industry; this analysis resulted in the identification of one strength, six weaknesses, eight opportunities, and seven threats to the RWP. The second phase of the methodology consisted of developing a model to bridge the gap between the current RWP and what it needs to become. It resulted in eight Focus Areas (FAs) that were based on the findings from the SWOT analysis; each FA represents a unique theme of practical recommendations for improving the program. As a result of this research, maintenance managers have a practical tool to help evaluate and modernize their facilities and infrastructure PM strategy. Additionally, the Air Force has a model for modernizing its RWP.

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Ross E. Dotzlaf

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FOR FACILITY AND INFRASTRUCTURE MAINTENANCE

## 1. Introduction

The primary objective for managers of facility and infrastructure maintenance is reducing the adverse effects of breakdowns and maximizing facility availability for the lowest cost possible (Sheu & Krajewski, 1994). Under most circumstances though, infrastructure operability is directly related to the expenditure of resources: a higher level of operability requires more resources while lower expenditure of resources usually results in a diminished level of operability. Fortunately, there are ways for maintenance managers to intelligently apply their resources to attain higher levels of operability for lower proportional increases in the amount of resources expended – one such method that is commonly utilized is preventive maintenance. Preventive maintenance (PM) is defined as regularly scheduled maintenance actions that are based on average failure rates of the components of an asset (Sheu & Krajewski, 1994). Although PM requires routine planning and analysis in order to ensure a consistent, optimal balance between resource expenditures and infrastructure operability, a properly implemented PM strategy can lead to many benefits in terms of equipment life, resource expenditures, and work scheduling. Periodic evaluation of a PM strategy can help identify ways to modernize a maintenance program by improving its efficiencies and maximizing its potential effectiveness (Brown, 2003). For this thesis research effort, such an evaluation was performed on the United States Air Force's infrastructure and facility PM program known as the Recurring Work Program (RWP). The purpose of this case study was to serve as a model for modernizing a PM strategy.

**Background**

The primary intent of PM is to prevent common equipment failure modes, and it is particularly useful when the risk of failure is unacceptable (Hiatt, 2003). These maintenance actions can take many forms, to include inspections, adjustments, calibrations, cleaning, lubrication, replacements, and rebuilds (Brown, 2003; Dunn, 2007). PM will extend the expected life of equipment and enable equipment to run more efficiently, thereby decreasing the chance and number of catastrophic failures; this will result in maintenance and capital cost savings (Sullivan, Pugh, Melendez & Hunt, 2004). Furthermore, since equipment failures can lead to unscheduled work stoppages, PM helps enhance operability.

A truly optimal PM strategy in terms of balancing infrastructure operability and resource expenditures may not be realistically attainable in a resource constrained environment. For a given level of resources, there is a limit to the amount of work that can be performed. When this limit does not provide the necessary level of infrastructure operability, there is a certain amount of risk involved with where and how managers decide to allocate their maintenance resources. For this reason, maintenance managers must routinely evaluate and update their PM programs in order to minimize risk while ensuring the optimal balance between resource expenditures and realized benefit (Brown, 2003). Excessive PM can consume resources needed for other types of work; conversely, insufficient PM can lead to the same results as no preventive maintenance – higher chances of unplanned equipment failures, shorter equipment life cycles, and higher operating costs (Sullivan et al., 2004).

PM programs can be found within the maintenance operations of a wide variety of organizations, from large private sector organizations like General Motors (Culver, 2007) to small public sector organizations like the Anoka-Hennepin School District in Minnesota (Office

of the Legistlative Auditor, 2000). While public sector maintenance operations are usually gauged on how far the budget can be stretched, private sector maintenance operations are traditionally gauged against the organization's profits. Given the cost savings potential, both public and private sector maintenance operations stand to gain from of a properly implemented PM strategy.

The United States Air Force is a large public sector organization with numerous installations and a vast inventory of facilities and infrastructure. Within the Air Force, the Civil Engineer (CE) function is responsible for providing installation and mission support, and within a standard CE unit the Operations Flight is responsible for facility and infrastructure maintenance, to include the RWP (Air Force Civil Engineer Support Agency (AFCESA), 1998). The primary guidance for the RWP is provided in Air Force Pamphlet (AFPAM) 32-1004, Version 2, and subsequent guidelines exist in numerous CE references. These guidelines are very helpful in explaining the potential benefits of a properly implemented program and provide basic instructions for establishing, integrating, and updating an RWP. However, these general guidelines are only helpful to a certain extent because they lack specific details and do not provide bounds for the size and scope of an individual program. As a result, the RWP has become a very individualized program that varies greatly from base to base in terms of the type and quantity of equipment maintained, as well as scope and frequency of maintenance actions.

Due to the financial strain of an on-going war on terror, aging aircraft, and a shrinking budget, Air Force leaders stress the importance of optimizing every facet of operations to include facilities and infrastructure – "since funding available for installation support has been reduced by 20% since FY2006, CE must now achieve offsetting efficiencies to ensure that installations remain capable of enabling Air Force missions" (Culver, 2007). Maximizing the effectiveness of

the RWP is extremely important because when resources are constrained, PM work is the first to be displaced from the schedule in light of emergency or more noticeable work (Brown, 1999). If PM work is not being completed, management must understand the associated level of risk and be able to make appropriate decisions to minimize that risk. It is of utmost importance to ensure that the RWP is able to provide the highest return for the time and resources invested with the minimum amount of risk in order to secure the program's existence and help the Air Force capitalize on all of its potential benefits.

As it transitions into the 21st century, the Air Force is taking every opportunity to maximize the efficiency of its operations by learning from the private sector and implementing the latest management concepts (Wynn, 2006). Standard catch phrases like "doing more with less" and "working smarter, not harder" are no longer just popular management slogans; rather, they have become an operational necessity for the military to stay in operation. In an attempt to champion efforts to eliminate waste and increase efficiency, the Air Force has fielded an initiative known as Air Force Smart Operations for the 21st Century (AFSO21 Office, 2007). AFSO21 encourages leaders at all levels to look within their units and ask the tough questions that get to the heart of what they do and how they do it (Wynn, 2006; Gaub, 2007). The RWP is an existing Air Force program that could benefit from an AFSO21 modernization and could help the Air Force utilize its resources more effectively. For a more thorough understanding of the background of the program, a brief history of the RWP is located in Appendix A.

Many organizations will be able to generalize the results of this study to their own PM program because the concerns facing the Air Force are not unlike the current concerns facing many other large organizations. Furthermore, many of these large organizations also possess a vast array of facilities and infrastructure, as well as an extensive PM program to sustain them.

This case study evaluation of the Air Force RWP will not only address the organizational need to improve program efficiency, but also the routine need to periodically evaluate the program to identify opportunities for improvement.

**Problem Statement**

The Air Force RWP was evaluated to address the organizational need to enhance the efficiency of the PM program. Specific attention was given to addressing four operational concerns facing the RWP that were described in the background section. The first concern relates to resources – Civil Engineer units are facing budget and manpower constraints that are not conducive to sustaining an extensive RWP. Therefore, the program must be optimized to provide the highest level of infrastructure and facility operability for the set amount of resources devoted to maintenance. The second concern is associated with organizational changes that affect the responsibility for the program. A recent reorganization of the CE squadron has separated the section traditionally responsible for management of the RWP from the section responsible for its implementation; therefore, the most efficient methods for managing and implementing the program must be identified. The third concern is associated with risk – impending resource constraints will likely make it difficult to support even the most optimally efficient RWP. Thus, the program should account for risk and help managers make decisions that minimize overall risk while providing the highest productivity for the amount of resources allocated to the program. The fourth concern is based on organizational necessity to improve effectiveness in all facets of operations. AFSO21 is causing a shift in the way the Air Force does business, and every aspect of operations must be thoroughly analyzed and updated to eliminate waste and maximize efficiency. The recurring work program has the potential to provide

significant benefits in terms of resource conservation and mission support capabilities. By evaluating the program to address the current concerns and enhance operational efficiency, the Air Force can take advantage of all potential benefits of the RWP.

**Research Questions**

There were two primary research questions for this study. The first question was: "what is the state of the current RWP?" Answers to this question established the positive and negative aspects of the current program and identified desired capabilities of a modernized RWP. These answers also provided a basis from which to address the second question, which was: "how should the RWP be improved?" This basic question drove the entire thesis effort and provided an open-ended forum to address all concerns with the RWP and modernize the Air Force's PM strategy.

**Methodology**

This study was divided into two phases that paralleled the two research questions previously mentioned. The first phase, intended to develop an understanding of the current program and how it needs to change, consisted of two segments. First was a data collection effort which consisted of interviews with members of the Air Force CE community who have extensive experience with the RWP. Using information from the data collection and literature review (discussed in Chapter 2), the second segment of the first phase of the methodology consisted of a strengths, weaknesses, opportunities, and threats (SWOT) analysis of the RWP. The purpose of the SWOT analysis was to provide a solid understanding of the current program and a framework from which to improve the program. While the four previously identified

concerns with the Air Force RWP are certainly relevant, this analysis reached even deeper into the existing program to identify all potential areas for improvement in order to provide the most complete solution possible.

While the first phase identified the gaps between where the program is and where it needs to go, the second phase identified a strategy to bridge the gaps and renew the program. In this phase of the study, a model for modernizing the RWP was developed by compiling, de-conflicting, and strengthening the recommendations from the SWOT analysis to produce a manageable number of focus areas. Each focus area represents a unique theme of practical recommendations for improving the program. To support ideas suggested in the focus areas, a series of implementation concepts were also developed.

**Assumptions**

There were three assumptions that provided a framework for this research. First, it was assumed that the existing RWP at each base was developed based on the general RWP framework provided in official Air Force guidance. Additionally, all maintenance theories and best practices garnered from industry and academia were applicable to the Air Force and the RWP. Last, despite inherent differences between environmental conditions, operating conditions, and missions at different bases across the Air Force, the findings and recommendations developed during this study were assumed applicable to all units.

**Limitations**

There are a number of limitations that bounded the results of this study. The primary limitation was time. Since variations in maintenance practices can take months or years to

generate noticeable effects, the relatively short timeframe of this study did not allow direct comparison between different maintenance practices. Another limitation was the poor quality of existing data. As will be discussed in the thesis, schedule/completion data for the RWP is very unreliable and could not be analyzed to support any solid conclusions. A third limitation of this study is the variation between Air Force installations which can include differences in location, mission, population, environment, available resources, commander priorities, age of facilities, number or total area of facilities, and more.

### Significance of Study

This study will contribute to the academic body of knowledge and the facility maintenance community by providing a model for evaluating and modernizing a PM strategy using a structured analysis to apply relevant maintenance management theories and concepts to a large public sector maintenance operation. Unlike much of the academic literature in this topic area, this study is aimed at practical application of the findings rather than expounding upon theoretical concepts. For the Air Force, the results of this study provide the foundation for transforming the current RWP to improve the operational efficiency and effectiveness of CE facility and infrastructure maintenance.

### Organization of Remaining Chapters

Following this introductory chapter, there are four additional chapters to this thesis. The second chapter consists of a literature review that covers various topics relevant to maintenance management. The third chapter is a detailed overview of the methodology for the study, to include data collection, SWOT analysis, and model development. Results and discussion are

presented in the fourth chapter, which explains all the findings from the SWOT analysis and provides a detailed description of each focus area from the model.  The final chapter serves as a conclusion to the study and reviews all important details from the entire thesis process.

# 2. Literature Review

The purpose of the literature review was to identify and analyze documents containing information relevant to modernizing a preventive maintenance (PM) strategy for facilities and infrastructure. This chapter provides an overview of the relevant information examined in this literature review, and it consists of six primary sections. The first section focuses on maintenance management; it offers a framework from which to understand the basic concepts behind maintenance and the reasons for proper maintenance management. The second section focuses on four maintenance strategies relevant to this study – reactive maintenance, preventive maintenance, predictive maintenance, and reliability centered maintenance. Maintenance optimization models and their utility in maintenance management is the topic of the third section, while a brief overview of decision modeling and analysis is provided in the fourth section. The fifth section focuses on asset management and its relevant themes that apply to modernizing a PM strategy, and the final section compares applied maintenance practices in order to identify practical ideas and insight about how to evaluate and modernize a maintenance strategy.

## Maintenance Management

The first section of the literature review explains the concept of maintenance management. It offers a framework from which to understand the underlying principles of maintenance, and it clarifies the role and impacts of management on a maintenance operation. An understanding of this topic is essential to this thesis because any effort associated with having, evaluating, or modernizing a maintenance strategy is encompassed within the field of maintenance management.

Maintenance is defined as “any activity carried out on an asset or system in order to ensure that it will continue to perform its intended functions” (Dunn, 2007). Maintenance activities can be technical or administrative in nature, and they include any effort to protect, preserve, or prevent a system from decline (Smith, 2000; Dekker, 1996). Regardless of construction and durability, all buildings, equipment, and infrastructure require responsible operation and some amount of periodic maintenance; failure to perform intended maintenance will shorten the operating life of these assets (Whole Building Design Group Sustainable Committee, 2007; Sullivan et al., 2004).

In many maintenance organizations, daily activities are often dominated by unplanned events (Dekker, 1996). However, organizations rarely have adequate resources to address all unplanned events and perform all scheduled maintenance actions on infrastructure and equipment assets. Scheduled maintenance that goes uncompleted is known as deferred maintenance. In addition to the sum of all maintenance deficits, deferred maintenance also includes the compounding negative effect on the assets (Vanier, 2001). Accumulation of deferred maintenance can eventually destroy a maintenance operation when the resources required to meet the maintenance deficit become greater than the resources available for the entire maintenance operation (Brown, 1996). Furthermore, as deferred maintenance accumulates, unplanned maintenance requirements increase and further expand the overall maintenance deficit and risk of premature system failures (Vanier, 2001). In order to avoid the serious threats of deferred maintenance, organizations rely on the study and application of maintenance management.

The primary conflict facing managers of maintenance operations is the struggle of maximizing equipment availability while minimizing resource expenditures (Lin, Hsu &

Rajamani, 2002). Additionally, maintenance operations are often constrained by external factors and increasing maintenance resources is rarely an option (Turner, 2002). Since maintenance consists of many different activities, management gets increasingly difficult as the scope of maintenance operations grows (Dekker, 1996). In an attempt to combat these challenges, organizations have turned to the study of maintenance management, which focuses on reducing the adverse effects of breakdown and maximizing facility availability at minimum cost while operating within environmental constraints (Sheu & Krajewski, 1994). Competent and effective maintenance management will have a direct, positive impact on the profitability and reputation of any organization (Ahire, Greenwood, Gupta & Terwilliger, 2000).

There are four primary objectives of maintenance management – system function, system life, safety, and what is known as 'human-well being' (Dekker, 1996). The first objective, system function, refers to ensuring an equipment asset or production system is reliable, available, efficient, and capable of serving its intended purpose. Next, system life refers to managing the system as an asset and keeping it in proper working condition. The third objective, safety, focuses on ensuring risks are kept within acceptable limits and/or meet statutory requirements. Last, 'human well-being' refers to fulfilling a psychological need that has no direct fiscal or technical necessity.

Maintenance management programs can vary greatly depending on the context of the maintenance operation (Ahire et al., 2000). There are three primary factors that determine the context: the characteristics of the system being maintained, the goals of the maintenance managers, and the scope of the maintenance operation. System characteristics include such factors as the type, age, and operating hours of the equipment. Goals are the intended outcomes of the maintenance operation and can focus on various aspects such as minimizing costs,

maximizing effectiveness, or avoiding breakdowns. Scope refers to the size of the maintenance operation and the type of intervention that will occur on the system. There are two types of interventions – minimal repair and preventive maintenance. Minimal repairs take place when failures occur, while preventive maintenance is performed according to a pre-determined schedule (Bartholomew-Biggs, Christianson & Zuo, 2006).

## Maintenance Strategies

Each maintenance operation has its own unique management approach. Although one particular maintenance strategy can dominate a given maintenance operation, a combination of strategies is more typical. This section of the literature review spotlights the four most common maintenance strategies – reactive maintenance, preventive maintenance, predictive maintenance, and reliability centered maintenance. An understanding of these is important to this thesis because it provides ideas for modifying a maintenance management approach, as well as insight into which strategies are optimal for different situations.

### *Reactive Maintenance*

Reactive maintenance is defined as those maintenance actions taken to fix a component when it reaches functional failure (Turner, 2002). It is also known as corrective maintenance, since it is performed purely to 'correct' failed or deficient equipment. Rather than performing maintenance actions to ensure design life is reached, reactive maintenance employs the "run it till it breaks" mentality (Sullivan et al., 2004).

Reactive maintenance is particularly effective for non-critical, low-cost system components and equipment (Pride, 2008). As such, reactive maintenance should be used

whenever the cost of maintaining an asset exceeds the asset's replacement value, unless the risk associated with failure is too severe. Reactive maintenance also provides benefits for small maintenance operations when the staff is not large or qualified enough to adequately perform routine maintenance activities (Sullivan et al., 2004). Despite these advantages, there are numerous disadvantages to reactive maintenance.

The primary disadvantage of reactive maintenance is the high risk of unscheduled failures. Unscheduled failures require more time and money to correct, especially if overtime labor is required to correct the problem (Sullivan et al., 2004). In addition, the opportunity cost of lost productivity from unplanned equipment downtime must also be included. A further risk of reactive maintenance is the potential for secondary system damages that may result from equipment failure. While reactive maintenance may seem to save maintenance and capital costs, it is an inefficient use of staff resources and has been shown to have higher long-term costs than other maintenance approaches (Sullivan et al., 2004).

As with deferred maintenance, the compounding effects of reactive maintenance can have negative effects on the overall maintenance operation; this situation is known as the reactive maintenance spiral (Turner, 2002). The premise of the reactive maintenance spiral is that successive preventable failures consume resources to the extent that the maintenance operation can only afford less-expensive, temporary repairs. In turn, these repairs have a higher probability of preventable failure which eventually consume even more resources, and the cycle continues. This potential pitfall poses a serious threat to maintenance managers; however, it can be avoided by ensuring reactive maintenance is only applied in the appropriate context.

In addition to only using reactive maintenance when appropriate, the risks associated with reactive maintenance can be reduced by speeding the repair service, easing the task of

repair, and providing alternate output during repair time (Turner, 2002). There are a number of ways to accomplish these effects, to include: increasing maintenance crew size, creating spare parts and redundant equipment inventories, designing equipment and systems to facilitate maintenance, and improving craftsman training. Faster repairs correlate with lower labor costs, and less equipment downtime helps minimize the opportunity cost of halted production.

*Preventive Maintenance*

Preventive maintenance is defined as regularly scheduled maintenance actions performed on equipment and infrastructure systems to prevent wear and degradation, extend useful life, and mitigate the risk of catastrophic failure (Sullivan et al., 2004; Alaska Department of Education & Early Development (ADEED), 1999; Lewis, 1991; Kay, 1976). Unlike reactive maintenance which takes place when a failure occurs, PM actions are performed at an established frequency. These frequencies are based on average failure rates of equipment using either equipment run time or calendar time, and maintenance actions are accomplished prior to expected failure (Quan, Greenwood, Liu, & Hu, 2007; Industrial Accident Prevention Association (IAPA), 2007). PM is particularly effective when the risk of system failure is unacceptable or when reliable data for maintenance versus equipment failure is available (Pride, 2008).

There are numerous advantages of PM; the two most cited ones are an increase in average equipment life span and a decrease in the risk of catastrophic equipment failure (Sullivan et al., 2004; IAPA, 2007; Lewis, 1991). By helping equipment run more efficiently, preventive maintenance can also lead to energy savings, higher equipment output and safety, lower environmental impacts, and increased facility operability (Lewis, 1991; Sullivan et al., 2004). The planning and scheduling practices associated with PM encourage management to be more

proactive, standardize maintenance procedures, improve spare parts inventories, decrease system downtime, and make maintenance operations more efficient and flexible (Lewis, 1991; IAPA, 2007; Yao, Fu, Marcus, & Fernandez-Gaucherand, 2001). Each advantage of PM is correlated to financial benefits for the practicing organization, such as lower capital costs, fewer replacements, less equipment downtime, and energy savings (Sullivan et al., 2004; IAPA, 2007; Magee, 1988; Lewis, 1991).

Although PM offers a wealth of advantages for maintenance operations, it is not without its disadvantages. The primary disadvantage is that catastrophic failures are still likely to occur, regardless of the decrease in the risk of equipment failure from preventive maintenance (Sullivan et al., 2004). As such, a maintenance operation must still be able to respond to emergencies and cannot rely solely on PM. Extensive PM programs require a large amount of labor resources, and there is often a probability of performing excessive maintenance that has no positive impact on the equipment (Sullivan et al., 2004). Furthermore, it is extremely difficult to determine the optimal level of preventive maintenance, and it may require years of maintenance actions and data collection before payback is realized (Idhammer, 2008; Chen, 1997). Since its impacts are often less visible than other types of work, PM is often the first work to be skipped in light of emergencies or other requirements that may seem more important (Brown, 1996). While the impacts of such a decision may not be immediate, it can drastically impact the overall effectiveness of a PM program.

Preventive maintenance programs can vary greatly depending on the context in which they are implemented; however, there are a number of characteristics that can be used to describe the differences between programs. PM actions can be either simple or replacement – while replacement actions improve the reliability of a maintained asset to that of a brand new system,

simple actions only improve the reliability to some small degree. Whether simple or replacement, PM actions can be assigned one of three levels of priority: critical actions are those that will lead to immediate loss of facility function if not completed on time, required actions are those that can be postponed for a short period with no major impact on a facility, and discretionary actions are those that can be deferred indefinitely with no major impacts on a facility (Magee, 1988). There are five primary reasons for implementing a preventive maintenance program: sustain operations, lengthen equipment service life, identify equipment degradation, prevent equipment loss, and comply with standards (Magee, 1988). These reasons are directly related to the numerous potential advantages of preventive maintenance, and most programs will be established to meet a combination of these objectives.

When implementing a PM program, the first step is to identify the equipment that will be maintained (ADEED, 1999). Equipment assets and systems with high downtime, high maintenance, or repetitive repairs are ideal candidates for preventive maintenance (Brown, 2003). Subsequently, the equipment must be evaluated to determine its current condition and then ranked for maintenance priority among all candidate equipment (ADEED, 1999; Westerkamp, 1997). Criteria for defining maintenance priorities include the equipment's impact on organizational mission, safety risks, maintenance costs, and operational costs (Turner, 2002). Once the equipment and priorities for the PM program have been established, work actions for each activity must be defined (Westerkamp, 1997). Traditionally, each identified preventive maintenance action should consist of an established frequency, a description of the maintenance task, a list of necessary tools and equipment, and safety considerations (Quan et al., 1999).

Establishing preventive maintenance actions can be a daunting task for the untrained maintenance manager; however, there are a number of available sources of information to assist

with this process.  The most common source of preventive maintenance information is manufacturer or vendor recommendations (ADEED, 1999).  In many cases, a manufacturer's warranty is dependent upon implementation of the recommended maintenance plan (Magee, 1988).  Nevertheless, managers should not blindly use the manufacturer's recommendations in their original form because they may not align with the organization's goals or be optimized for certain environments (Brown, 2003).  Another source of information is the tacit knowledge of maintenance personnel which is based on craftsman experience working with the equipment and infrastructure (Brown, 1999).  A third source of preventive maintenance information comes from industry guidance (ADEED, 1999; Brown, 2003).  Although detailed guidance may not be available for a specific piece of equipment, information regarding general classes of equipment or similar equipment items can be modified to fit a specific facility requirement (Brown, 2003). A fourth source of preventive maintenance information is test results from impact analysis and/or failure analysis (ADEED, 1999).  While failure analysis focuses on necessary actions to delay equipment failure, impact analysis focuses on mitigating the potential effects of equipment failure on an organization's mission or resources (Magee, 1988).

In addition to maintenance frequency and scope recommendations, PM sources also suggest various actions and procedures.  One type of preventive maintenance procedures consists of inspections and testing (Quan et al., 2007; Dunn, 2007).  These actions can be performed using human senses, gauges, and unique instruments; they are intended to verify that the equipment is performing according to specifications (Brown, 2003).  A second category includes adjustments and calibrations (Quan et al., 2007; Dunn, 2007).  These actions are intended to optimize equipment operation and correct any deviations from standard performance (Brown, 1999).  A third category consists of rebuilds and replacements (Quan et al., 2007; Dunn, 2007).

These actions include periodic replacement of worn or disposable parts, and they are intended to restore equipment to optimal condition (Brown, 2003).

*Predictive Maintenance*

Predictive maintenance is defined as a process of determining maintenance action requirements according to regular inspections of an equipment asset's physical parameters, degradation mechanisms, and stressors in order to correct problems before failure occurs (Sullivan et al., 2004; Brown, 1999). Also known as conditions-based maintenance, this strategy differs from preventive maintenance in the fact that maintenance actions are performed according to the physical condition of the equipment, rather than an established frequency (Kwak, Takakusagi, Sohn, Fujii & Park, 2004; Lin et al., 2002). Predictive maintenance works particularly well for systems that are easy to monitor and have easily identifiable characteristics that can be statistically analyzed to determine remaining system life (Lin et al., 2002).

The advantages of predictive maintenance are numerous (Sullivan et al., 2004). Predictive maintenance actions primarily consist of simple inspections which are rarely labor intensive and seldom require equipment downtime (Lin, et al. , 2002; Westerkamp, 1997). These benefits correlate to conserving maintenance resources and minimizing impacts on facility operations. Since physical maintenance is only performed when conditions warrant, unnecessary maintenance actions are also prevented. This, in turn, allows maintenance operations to shrink material inventories, optimize work order scheduling and labor allocations, and improve the quality of equipment maintenance (Sullivan et al., 2004; Westerkamp, 1997).

Despite its advantages though, predictive maintenance is not without a handful of disadvantages. As with preventive maintenance, predictive maintenance will drastically reduce

the risk of catastrophic equipment failure, but it cannot eliminate the risk. In addition, predictive maintenance requires a significant initial investment in terms of diagnostic equipment and staff training (Sullivan et al., 2004). While predictive maintenance is applicable to many types of equipment and infrastructure, the techniques for calculating remaining service life can be difficult or unreliable for some systems (Brown, 1999). Consequently, it can sometimes be difficult for management to realize the savings potential of predictive maintenance (Sullivan et al., 2004).

Predictive maintenance relies on assessments of equipment or infrastructure condition; it can be applied to nearly any equipment problem where a physical parameter can be measured (Brown, 1999). There are numerous measurement devices used for predictive maintenance; some of the more common devices include pressure and temperature gauges, leak detectors, vibration and gas analyzers, and electrical tong testers (Westerkamp, 1997). When establishing a predictive maintenance program, it is critically important to establish condition limits or rates of change in order to have a standard by which to compare measurements. As long as the limits are appropriately set, there will be plenty of time to correct any problems and avoid equipment damage (Brown, 1999). Established limits for many types of equipment are provided by manufacturers, professional societies, and/or industrial groups. An understanding of equipment lifecycle can be helpful when establishing limits; most equipment lifecycles adhere to a standard behavior known as the bathtub curve for equipment mortality, as shown in Figure 1 (Brown, 1999). Furthermore, the predictive maintenance process is fairly simple; once measurement limits are set, the continual monitoring and repair work flows as depicted in Figure 2.

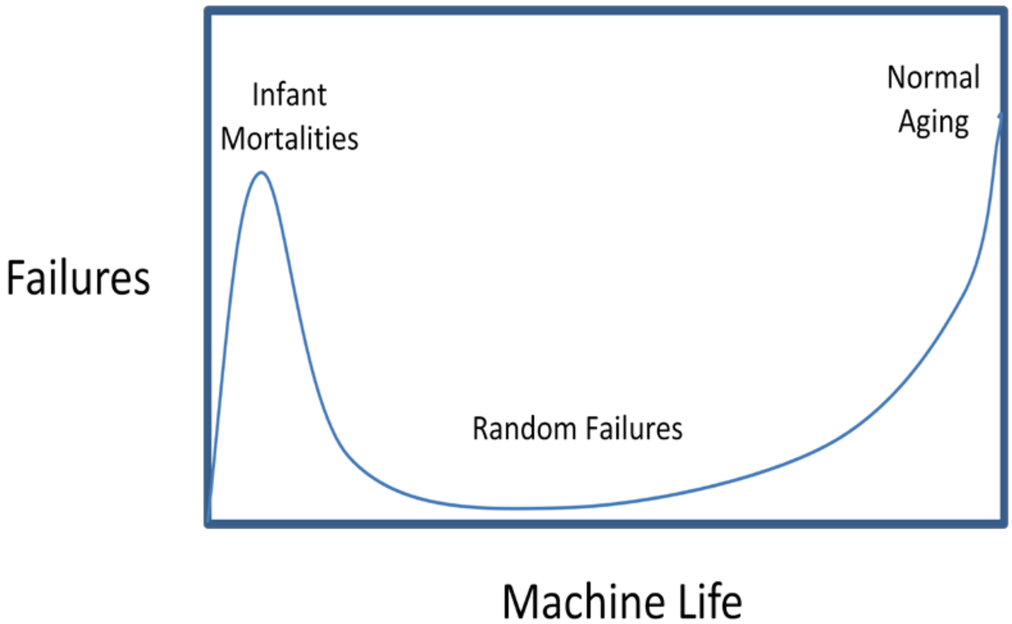


Figure 1. Bathtub Curve for Equipment Mortality (Brown, 1999)

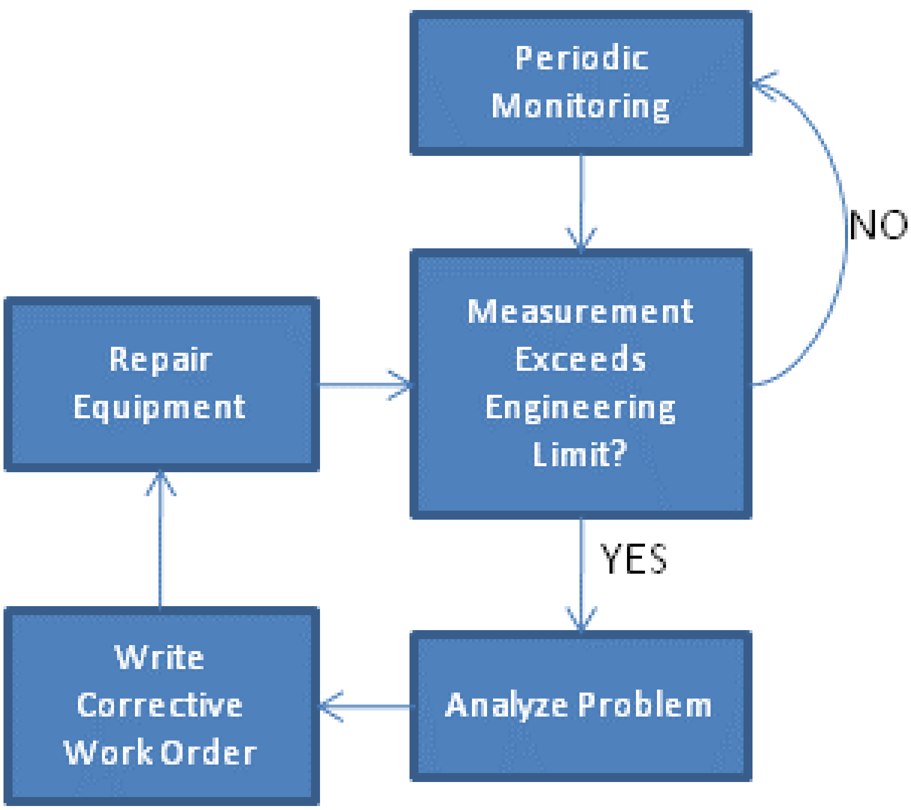


Figure 2. Predictive Maintenance Process Flow Chart (Brown, 1999)

*Reliability-Centered Maintenance*

Reliability-Centered Maintenance (RCM) is a process that directs maintenance efforts at the equipment and systems where reliability is critical in order to ensure the highest level of facility effectiveness (Turner, 2005). RCM uses a systematic approach to evaluate the causes and effects of equipment failure, which is then used to compare equipment needs with available resources (Sullivan et al., 2004; Carretero et al., 2003). RCM is particularly effective in situations when all of the equipment in a facility is not of equal importance to operations or safety, different equipment has different failure mechanisms and failure probabilities, and the organization has limited financial or manpower resources (Sullivan et al., 2004).

There are three major goals of RCM (Carretero et al., 2003). The first goal is to enhance the safety and reliability of systems and infrastructure. This is accomplished by focusing on the systems that are most critical to the organizational mission and operations. The next goal is to prevent or mitigate the consequences of equipment failures. Rather than preventing the actual failures, RCM focuses on protecting the entire system. The third goal is to reduce maintenance costs. This is accomplished by avoiding or removing maintenance actions that are not strictly necessary for normal system function.

RCM has numerous advantages over other maintenance strategies. In many cases, RCM has proven to be the most efficient maintenance program (Sullivan et al., 2004). Although RCM does not provide a truly optimized maintenance strategy, it does help ensure resources are directed where they can be the most efficient and effective for the organization (Berger, 2004). As with other strategies, RCM cannot eliminate the risk of equipment failure; however, it can help reduce the probability of failure. Furthermore, when unexpected failures occur, RCM helps ensure the negative impacts are minimized (Sullivan et al., 2004). By eliminating unnecessary

maintenance actions, RCM also helps to conserve maintenance resources and improve labor effectiveness.

Despite its advantages, there are some disadvantages to RCM which are mostly related to implementation aspects rather than the methodology itself (Carretero et al., 2003). Due to the fact that RCM seeks to analyze the failure modes on each piece of equipment, the primary disadvantage is the large amount of resources, time, and energy required to establish a new RCM program (Carretero et al., 2003; Sullivan et al., 2004). With numerous failure analyses for each system, the overwhelming majority of findings produce no maintenance requirements; this may appear to be a waste of time and resources since the savings potential is often difficult for management to see (Turner, 2002; Sullivan et al., 2004). Organizations often attempt to perform an RCM analysis on all equipment and expect short-term results; however, RCM was originally developed to address a small portion of an organization's equipment from a long-range perspective (Carretero et al., 2003). Similarly, the metrics that are often used to evaluate RCM are aimed at the equipment and failure modes; however, they should be directed at multiple levels throughout an organization (Berger, 2004). A particular challenge with RCM is its focus on maintaining equipment at a functional, rather than perfect state, which is often difficult for organizations to accept (Carretero et al., 2003).

When initiating an RCM program, the first step is to develop a list of all equipment that could potentially be included in the program (Sullivan et al., 2004). Since RCM can be time consuming and expensive, it is not realistic to apply it to each item on the list; therefore, the equipment must be identified as a candidate for RCM (Carretero et al., 2003; Sullivan et al., 2004). There are two measures that help with this classification – 'criticality' which measures the importance of a piece of equipment to the overall system and 'state' which represents the

current condition of the asset (Carretero et al., 2003). Once a piece of equipment has been determined to be a candidate for RCM, it is analyzed to determine the appropriate maintenance approach.

According to the RCM philosophy, the maintenance approach will depend on the equipment failure modes and failure effects. There should be several levels of failure analysis to identify effective maintenance tasks and mitigation strategies (Carretero et al., 2003; Sullivan et al., 2004). These levels include, but are not limited to, functional failures, failure modes, failure effects, failure consequences, and default actions; this multi-level analysis seeks to discover how a system can fail, why it fails, why it matters, and what can be done to keep it from happening (Turner, 2002). Based on the failure analysis, the equipment is prioritized for maintenance action. RCM maintenance actions can be reactive, preventive, or predictive in nature, and can be based on the manufacturer's recommendations, machine history, and good engineering judgment, among other sources (Sullivan et al., 2004).

The RCM process described above is fairly generic, and there are a number of tools that can assist with the decisions in the process. An example of an RCM "logic tree" is shown in Figure 3; it provides a good model for determining the correct RCM approach for individual equipment items (Pride, 2008). While there may be some variation between RCM initiatives depending on the organization, decision tools, and context of the maintenance operation, all RCM efforts have the same goal of optimizing maintenance operations (Carretero et al., 2003).

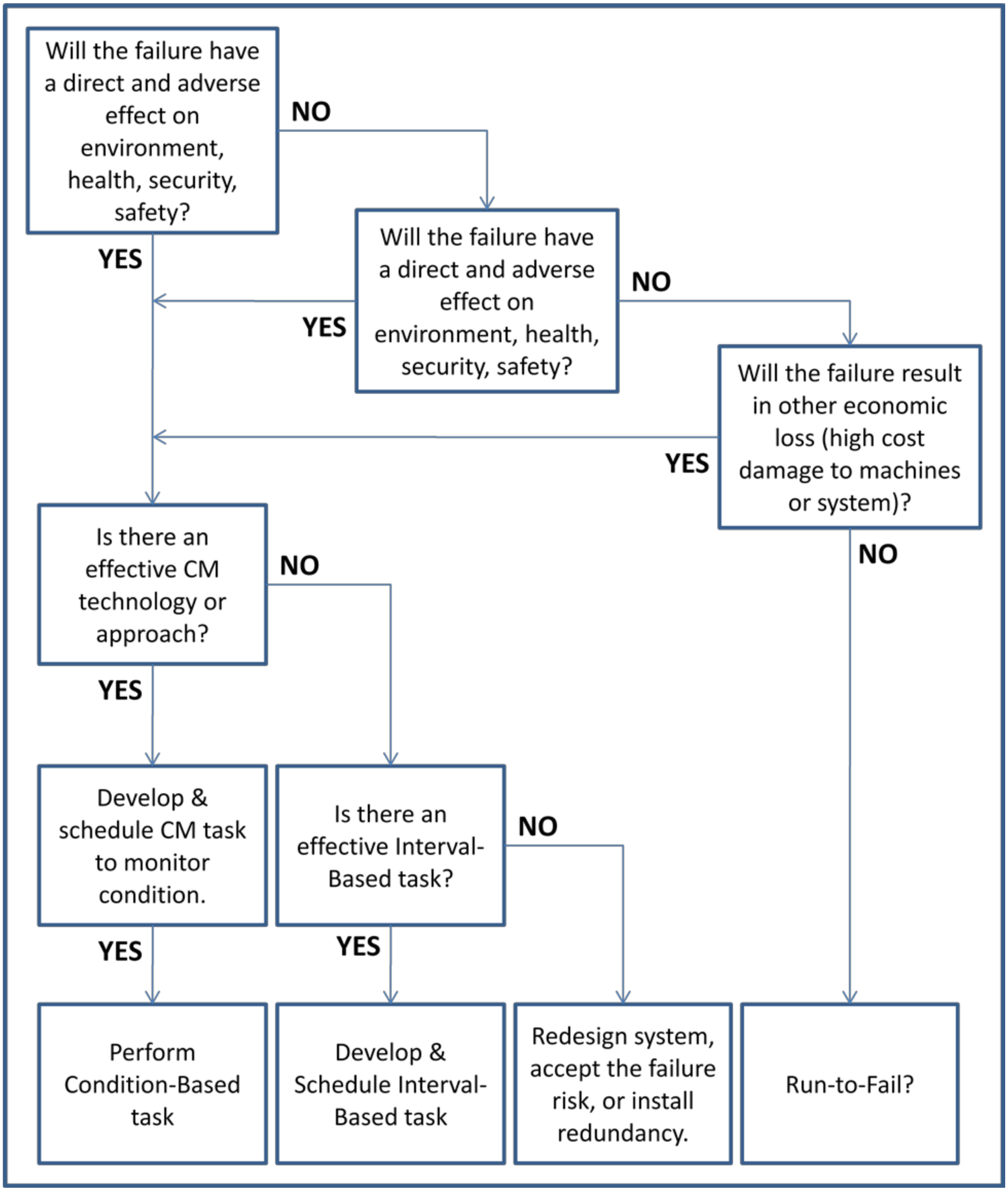


Figure 3. RCM "Logic Tree" (Pride, 2008)

## Maintenance Optimization

This section of the literature review discusses the concept of maintenance optimization. As previously discussed, the primary goal of maintenance management is to provide the highest level of facility and infrastructure operability for the lowest amount of resources possible. Maintenance optimization is a practice that uses mathematical models to assist with the decision-making process for maintenance implementation. These models combine reliability with economics by quantifying costs, benefits, and various constraints, and integrating the factors into basic economic methods (Dekker, 1996).

Maintenance optimization models can be designed to maximize or minimize various factors depending on the user and context of application; however, the overarching goal of all models is to find the optimal balance between resource expenditures and maintenance benefits (Dekker, 1995). These models are particularly helpful for comparing the cost-effectiveness of different maintenance policies, determining efficient inspection and maintenance frequencies, and incorporating numerous constraints into the decision making process (Dekker, 1996). This topic is highly relevant to this thesis because it provides insight into methods for achieving the primary goal of maintenance management. Maintenance optimization concepts should play an influential role in efforts to modernize a preventive maintenance strategy.

### *Traditional Optimization Model*

The traditional optimization model provides a simple, easy to understand example of how optimization models work (Berger, 2004; Idhammer, 2008). While the most useful models will optimize for multiple criteria, the traditional model only optimizes for one variable – cost. The model is represented using a two-dimensional graph, with cost on the vertical axis and mean time

between maintenance (MTBM) on the horizontal axis, as shown in Figure 4. From the figure, one can see that the preventive maintenance cost is dictated by an inverse relationship between cost and MTBM – for a higher MTBM there are fewer maintenance actions for a given time period, and therefore, lower overall costs. The cost of emergency repairs is based on the probability of equipment failure, which is driven by a direct relationship between cost and MTBM – for a lower MTBM, there are more maintenance actions for a given time period, and therefore, less chance for unplanned failure and lower emergency repair costs. The total expected cost of maintenance for a given MTBM is the sum of the preventive maintenance and emergency repair costs. This provides the basis for selecting the optimal maintenance frequency; logically, it is the MTBM associated with the lowest total expected cost of maintenance.

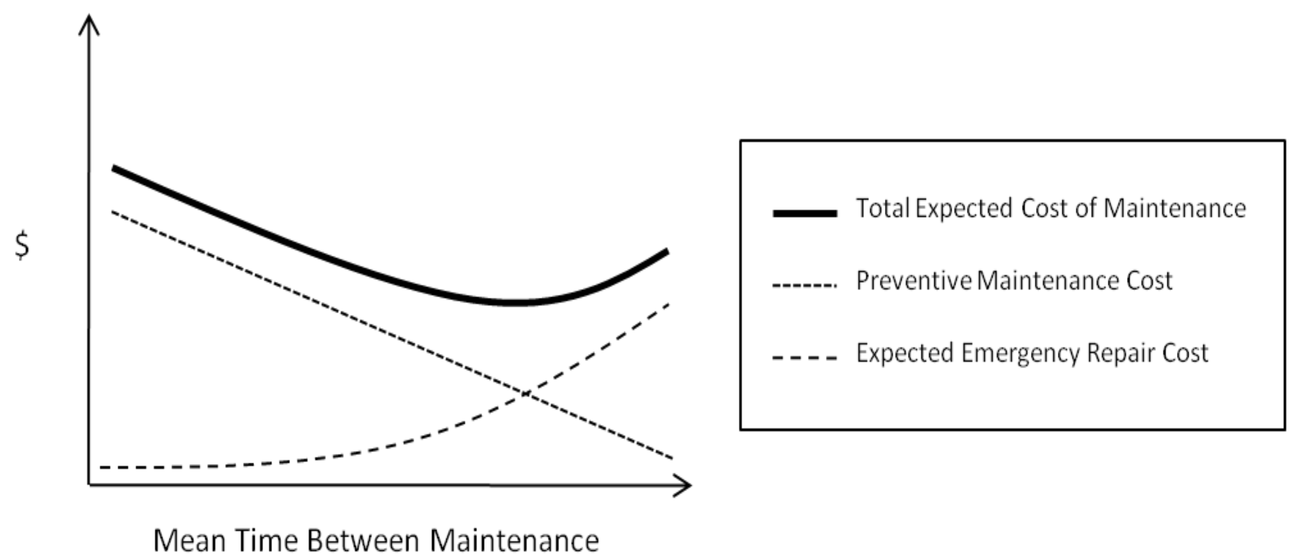


Figure 4. Traditional Maintenance Optimization Model (Idhammer, 2008)

The traditional model is very helpful in understanding the concept of maintenance optimization; however, it is not as practical in realistic applications for two reasons: it optimizes for only one variable and failure trends are rarely accurate. The optimal maintenance frequency

can vary depending on the variable being optimized; since the traditional model only optimizes for one variable, it could lead to incorrect conclusions and poor decisions for maintenance scheduling (Berger, 2004). Accurately modeling deterioration and the occurrence of failures in a system with respect to time is critical to maintenance optimization (Dekker, 1995). However, due to the fact that components rarely fail after a predictable time, it is very difficult to accurately depict equipment failure trends (Idhammer, 2008). Maintenance optimization models have evolved beyond this traditional model; however, avoiding these issues has played a significant role in the development of many current models and remains a limitation to others.

*Optimization Model Implementation*

As with all maintenance strategies, maintenance optimization models can vary greatly depending on the context in which they are applied. However, there are four common aspects of maintenance optimization models that are important to consider when developing a model for any system. The first aspect is a comprehensive description of the system being optimized, to include details about the system's function and its importance to the organizational mission (Dekker, 1996). The purpose of this aspect is to justify the need for the optimization model and identify the critical factors in the analysis. The next aspect is development of a system deterioration model to predict the lifecycle of the system; the model also helps determine the impacts of various maintenance frequencies on the system (Dekker, 1996). Additionally, a list of possible consequences of system failure is often associated with this aspect, due to the fact that different consequences can occur depending on the level of deterioration. The third aspect is a summary of available system information, which is used to lay the foundation for building the optimization model (Dekker, 1996). Often, a list of the various methods of system interaction

available to management is associated with this aspect; this can also be very useful for building the model. The final aspect is the objective function, which produces the output for which the model was developed (Dekker, 1996).

### *Advantages and Disadvantages*

Given the primary objective of maintenance optimization models, they have a number of obvious advantages. Foremost, the models provide a quantitative approach for identifying the most efficient balance of resource expenditures and maintenance benefits (Dekker, 1996). When analysis reveals no optimal solution, these models help determine candidates for reactive maintenance and the tasks to be eliminated (Turner, 2002). Similarly, these models can help identify which systems could be more efficiently managed by simpler or more advanced technology. During development, optimization models help users understand how to predict equipment life more accurately, which data to collect, and how to assess the level of risk for a given maintenance frequency (Turner, 2002; Idhammer, 2008).

While maintenance optimization models have obvious benefits, there are a lot of difficulties in application that can make the benefits hard to realize. These difficulties are among the numerous disadvantages of maintenance optimization models. Maintenance optimization models require massive amounts of performance and failure data that is often hard to obtain; maintenance craftsman may have significant knowledge about these aspects of the equipment, although it is often difficult to translate this knowledge into data (Dekker, 1996). When data is available, optimization requires a lot of detailed calculations that can be time consuming, hard to standardize, and difficult to validate. Further yet, the results of these calculations are rarely useful because a large amount of guesswork must be used to compensate for missing data or lack

of expert knowledge (Turner, 2002). Optimization calculations require the user to quantify all factors, to include the benefits of maintenance; however, many of the necessary factors are very subjective in nature and difficult to quantify (Dekker, 1996). Therefore, implementing an optimization model for an entire maintenance program with numerous pieces of equipment and systems is rarely feasible; the common tradeoff, which often leads to suboptimal outcomes, is a simplified approach that does not consider all factors (Vatn, Hokstad & Bodsberg, 1996).

An obvious gap exists between the potential benefits of maintenance optimization and the numerous disadvantages of its practical application; there are numerous reasons to explain this disparity. Due to the fact that most studies on maintenance optimization have been performed for purely academic purposes, maintenance optimization models can be difficult to understand and interpret (Dekker, 1996). Unless they have had prior experience, few academicians understand the needs of a practical maintenance operation. There are numerous different aspects of maintenance, and optimization models rarely focus on the right ones (Dekker, 1996). In some cases, maintenance organizations are not even interested in optimizing their operations, as certain redundancies and inefficiencies may provide a certain level of comfort (Dekker, 1996).

**Decision Theory**

The next topic in the literature review is decision theory, which is an area of research that provides a logical framework for solving real-world problems (deAlmeida & Bohoris, 1995). Through this framework, decision theory assists with analyzing a set of options in order to identify and select the best course of action in terms of potential benefit to the decision-maker (deAlmeida & Bohoris, 1995; Ragsdale, 2007). In the realm of maintenance management, decision theory is a valuable tool that is particularly helpful for prioritizing and scheduling work

requirements.  Managers are faced with numerous decisions on any given day, and their ability to make the best decisions will directly impact the productivity and effectiveness of the maintenance organization. With applications in nearly every aspect of maintenance operations, this topic is very relevant to this thesis and can provide valuable insight for making the tough decisions required when developing or modernizing a maintenance strategy.

Decision theory provides many benefits to the decision-maker.  Although it cannot ensure ideal outcomes result from every decision, decision theory provides a structured approach to decision making that can lead to a higher frequency of good outcomes than an unstructured approach (Ragsdale, 2007).  Furthermore, the structured approach does not strictly dictate the bounds of the framework and has some flexibility; it allows decision-makers to input their own objectives and knowledge of the problem to arrive at the best solution in their own terms (deAlmeida & Bohoris, 1995).  Another benefit of the framework is that it can be easily modified to incorporate new ideas, information, or requirements, all of which commonly occur (deAlmeida & Bohoris, 1995).  A further advantage of decision theory is that the structured approach provides a simple means for the decision-maker to communicate the logic for their choice, as well as for others to evaluate the decision-maker's justification (deAlmeida & Bohoris, 1995).

Despite its advantages, there are challenges associated with decision theory that should be understood by decision-makers.  As previously stated, decision theory cannot ensure that the outcome of every decision will be good.  While decisions are based on likely outcomes, there is always uncertainty about the future – even the best choices can have bad results (Ragsdale, 2007).  Additionally, decision theory allows decision-makers to personalize their decisions; however, individual knowledge, values, and objectives sometimes differ.   While this personal

aspect of decision theory is often considered a benefit, it can also serve as a disadvantage for controversial decisions that affect parties with different intentions (Ragsdale, 2007).

Within any decision problem, there are three types of factors: alternatives, criteria, and states of nature (Ragsdale, 2007). Each alternative is a course of action that is intended to solve a problem. In a decision problem, there must be at least two alternatives from which to choose; otherwise, there is no decision to make. Criteria are any relative factors by which the alternatives can be evaluated and compared. Each alternative in a decision problem must have at least one criterion by which to be judged, but it can have as many as the decision-maker is willing to analyze. States of nature are any events or conditions that have or can have an impact on the decision and are outside the control of the decision-maker (Ragsdale, 2007).

Implementing decision theory is a fairly straightforward process. The first step is to define the problem, to include analyzing the context and environmental conditions in which the problem exists (deAlmeida & Bohoris, 1995). The next step is defining the necessary information for the problem, which includes the three types of factors described above – alternatives, criteria, and states of nature. The third step in the decision-making process is determining the consequences or payoff of each alternative, given each potential condition; this information is used to develop the utility function. The fourth step is to develop a probabilistic model of the states of nature to provide a basis on which to compare the alternatives. The fifth step in the process is to perform the optimization calculations to determine the best combination of consequences and select an alternative. The final step is the sensitivity analysis, which is intended to validate the utility and consistency of the decision (deAlmeida & Bohoris, 1995).

**Asset Management**

Asset management is defined as a systematic process to optimally assess, allocate, and manage natural and built assets and their associated performance, risk, and expenditures over their life cycles in order to support missions, achieve organizational goals, and meet future requirements (Kleiser, 2008; Carley & Welch, 2008). Furthermore, asset management provides organizational leadership with a “decision-making tool that supplies information to take action on decisions such as how and when to acquire, maintain, operate, rehabilitate and dispose of or replace assets” (Carley & Welch, 2008). Asset management and maintenance management are highly interrelated concepts which are both concerned with making decisions that drive facility operability and consider its effect on the organizational mission. The next section of the literature review explains the concept of asset management. This concept is highly relevant to this thesis because it provides managers with the necessary insight and tools to incorporate numerous considerations when developing a maintenance strategy.

Organizations that have infused asset management into their culture and operations have benefited from its many advantages. One such advantage is that it helps to integrate information across multiple spectrums (Carley & Welch, 2008). Similarly, asset management forces organizations to plan and evaluate decisions from a ‘holistic’ view, which includes all of an organization’s assets instead of just portions or sections (Carley & Welch, 2008). Asset management also helps eliminate functional stove-pipes and encourages integration in all aspects of an organization (Carley & Welch, 2008). These advantages are particularly useful during strategic planning because they help ensure all assets are considered, utilized, and integrated in a manner that eliminates all conflicts and overlaps, such that an organization can optimize its asset

utilization. Nevertheless, asset management is not always easy; it requires hard work, time, energy, and tough decisions in order to produce results (Vanier, 2001).

When implementing an asset management plan, there are a handful of key concepts that are very helpful and will lead to success. The first is to manage real property from a portfolio perspective (Kleiser, 2008; Lawrence, 2007). Asset portfolios are initially developed by establishing complete accountability of all owned assets (Vanier, 2001; Lawrence, 2007). The next concept is to use key performance indicators, or metrics, to drive management decisions (Kleiser, 2008). Metrics should be collected for each asset and incorporated into the portfolio. Example metrics include the current condition of each asset and the amount of deferred maintenance; from this information, an asset's current worth and remaining service life can also be determined (Vanier, 2001). From the portfolio perspective, managers can consider and evaluate the interactions, performance indicators, and mission impacts of each asset, and make comparisons with the strategic goals and objectives of the organization. With this insight, managers can determine future plans for each asset and the organization (Vanier, 2001). The next concept is to develop standardized business processes and best practices across the organization (Kleiser, 2008; Lawrence, 2007). These processes stem from the structured decisions and plans made using the portfolio perspective.

Many private sector organizations have incorporated an asset management culture, and portions of the public sector have recently followed suit. For instance, Executive Order 13327 directs every department and agency within the executive branch to understand the importance of real property resources by incorporating asset management concepts in their respective policies and actions. In fact, there are distinct elements of asset management that every federal agency has been mandated to implement (Kleiser, 2008). In light of recent resource reductions and their

potential to impact future mission capabilities, the United States Air Force has determined that asset management is critical to its future (Kleiser, 2008). In its asset management approach, the Air Force emphasizes a few key concepts, to include systematic processes, integrated operations, optimized decisions, and complete asset lifecycle (Carley & Welch, 2008).

## Applied Maintenance Practices

In practice, most maintenance programs are comprised of and influenced by a combination of the various maintenance management strategies and concepts previously discussed in this literature review. Maintenance programs can vary since the makeup of each program is dictated by the operational context and needs of the organization. This final section of the literature review discusses and compares various applied maintenance management practices in order to provide ideas for modernizing a maintenance strategy in nearly any context.

First is a review of four categories of common pitfalls: management, workforce, reliance on established systems, and development of a maintenance strategy. The second through fifth topics include comprehensive planning, organizational support, program components, and metrics, respectively. Following that is a discussion of various best practices and rules of thumb that have appeared throughout the literature, while the last section consists of recommendations for successful organizational change implementation. All of these topics are relevant because they offer insight about effective maintenance management which should be considered when evaluating and modernizing a maintenance strategy.

*Common Pitfalls*

Maintenance managers face a number of potential pitfalls that can hamper the efficiency and effectiveness of a maintenance operation. Even though most of these pitfalls alone will not drive an organization to failure, positive results can be obtained more easily if they are identified and either avoided or corrected. Organizations that fail to recognize these weaknesses will likely experience poor performance; however, poor performance rarely lasts for very long – organizations either fix their problems or go out of business (Dekker, 1996).

The first category of common pitfalls is associated with management – both at the organizational level and at the maintenance operation level. Organizational management rarely understands the cost of asset ownership and the value of maintenance, so maintenance operations often do not get an adequate level of support in terms of manpower and resources (Smith, 2000; Turner, 2002). Maintenance managers, while they understand the value of maintenance, rarely have a robust knowledge of the condition of the facilities and infrastructure that they maintain (Vanier, 2001). As a result, they often use their limited maintenance resources inefficiently; furthermore, they are unable to justify the need for more resources to the organizational leaders who make the budget decisions. Additionally, a large portion of maintenance strategies are performed informally or outside a controlled system (Turner, 2002). When managers cannot maintain accountability of their maintenance operations, it become significantly more difficult for them to plan, organize, and control their resources.

Without a capable workforce, the best managers in the world cannot be effective, so the next category of common pitfalls is associated with the workforce. In many situations, maintenance personnel do not have the necessary skills to properly perform required actions (Smith, 2000). This can be attributed to many causes, to include inadequate education and

training, low hiring standards, and lack of on-the-job skills proficiency. Another cause of poor worker performance is lack of discipline or direction to follow established procedures (Smith, 2000). This problem can also be attributed to many causes, to include inadequate managerial oversight, lack of personal enthusiasm, and a poor work incentive structure. While workforce problems are often attributed to the individual workers, managers are equally responsible for contributing to these pitfalls, as demonstrated by the examples listed above.

Reliance on established systems or procedures makes up the third category of common pitfalls. Computerized maintenance management systems can be very helpful for organizing, tracking, and scheduling maintenance work; however, many users believe that the systems can accomplish more than they are capable (Turner, 2005; Rankin, 2003). Furthermore, users rarely understand how to operate these systems correctly, which results in schedules and other outputs that are less than optimal (Turner, 2005). Maintenance operations can also suffer from reliance on past procedures and reluctance to try new maintenance approaches. While the practices used by these organizations may be efficient and reliable, they may inadvertently keep the organization from utilizing new practices that could provide greater benefits.

The final category of common pitfalls is associated with the development, scheduling, and implementation of actual maintenance actions. When developing a maintenance action, adequate analysis of the equipment is rarely performed; this often results in tasks that either duplicate others or serve no purpose whatsoever (Turner, 2002). During scheduling of maintenance actions, failure to balance all requirements against available resources can result in maintenance tasks that are done too often, tasks that are done too late to have the intended effect, or tasks that are missed altogether (Turner, 2002). When the scheduling function completely breaks down, it results in a purely reactive maintenance strategy (Rankin, 2003). When

implementing maintenance actions, failure to use common sense and intuition can result in excessive work and consume unnecessary resources.  Although it may seem unnecessary to make this point, this pitfall occurs frequently; an example is performing an intrusive overhaul on a piece of equipment when a visual inspection would have been adequate (Turner, 2002).

*Comprehensive Planning*

Comprehensive planning is critical to the success of a maintenance program.  To be most effective, planning should focus on all levels of the organization and the relationships between them; assessing up, down, and across levels allows managers to optimize each individual level within the system (Berger, 2004).  Planning should also evaluate across all time horizons and address both the short-term and long-term needs of the organization (Office of the Legistlative Auditor, 2000).  Furthermore, planning should focus on the desired results of maintenance – minimizing failures and equipment downtime – and the work required to attain those results (Quan et al., 2007; Brown, 1999).

Before planning, it is imperative to collect a complete inventory of all maintainable assets and assess their conditions; subsequently, the planning process must also include a method for evaluating and ranking maintenance requirements (Office of the Legistlative Auditor, 2000). The evaluation method should analyze maintenance requirements from the system perspective, to include such aspects as system function, failure modes, failure consequences, and potential measures to prevent future failures (Turner, 2002; Pride, 2008).  When the evaluation system is applied to the completed inventory, managers can more easily identify maintenance priorities (Office of the Legistlative Auditor, 2000).

Plans should consider all maintenance strategies and potential maintenance actions, to include deliberate component replacement and exploratory maintenance (IAPA, 2007). Planning should be conducted throughout the lifecycle of the maintenance program, starting with initial development of the maintenance strategy. In order to ensure each aspect of a maintenance program is aligned, planning should be conducted simultaneously with scheduling and strategy revisions (Turner, 2002). Additionally, plans should be continuously reviewed and evaluated to reveal necessary modifications, identify gaps, and ensure maximum effectiveness (Magee, 1988). Managers can also proactively plan for the development and performance of future systems by providing feedback to equipment designers and builders.

*Organizational Support*

To ensure the success of any maintenance program, it must be supported by all levels of an organization; in some cases, "the best methodology in the world will fail if management staff and workers do not support it" (Carretero et al., 2003). Furthermore, organizational leadership in control of budget decisions must understand and support the maintenance program; otherwise, adequate maintenance resources may not be secured. Since management support is so critical to the success of a maintenance program, some organizations dictate specific requirements and assign individual responsibility for different aspects of their programs; this measure of accountability helps ensure success (ADEED, 1999).

As the individuals who implement the maintenance strategy, technicians and craftsman are critical to the success of a program. Even when personnel are fully qualified to perform proper maintenance practices, they may choose to not follow best practices. This lack of support can result in numerous failures and severely drive down the success of a maintenance program

(Smith, 2000). To ensure maintenance personnel support a program, they should be included in the strategy development and planning processes (Office of the Legistlative Auditor, 2000). In fact, their input can be a very valuable contribution to the maintenance program due to the fact that operational experience is a key driver for optimizing maintenance practices (Vatn et al., 1996).

In addition to the workers and managers, the customers and facility users who benefit from a maintenance program can contribute to its success. For example, simple equipment inspections can often be performed by the facility user, such that repair needs are only requested when needed (Magee, 1988). These actions encourage users to become actively involved in the maintenance program and help provide relief for the maintenance staff. A strategy known as Total Productive Maintenance (TPM) is built on user involvement; it expands beyond simple inspections by training users to also perform routine maintenance tasks (Chen, 1997). However, TPM is most effective in manufacturing applications where the users are in continuous contact with the maintained equipment, and it may not be applicable in all maintenance contexts.

One way to enhance organizational support for a maintenance strategy is to promote a reliability based culture in which the organization seeks to constantly improve maintenance methods by evaluating every task and failure (Turner, 2005). A reliability culture encourages a shift from a reactive to a proactive approach to maintenance. Rather than fixing problems, reliability seeks to improve a system to prevent problems; instead of responding to emergencies, reliability attempts to predict, plan, and schedule work (Dunn, 2007). The reliability culture also takes a more optimistic approach to maintenance goals – rather than minimizing equipment failures, the reliability approach aims to maximize equipment operational capacity (Dunn, 2007). To achieve the shift from a reactive to a reliability based culture, an organization must have a

long-term strategic focus and committed leadership; they must also encourage integration and foster teamwork by aligning reward systems with organizational strategic goals (Dunn, 2007).

*Program Components*

For any given maintenance program, there are many processes, tools, concepts, and other components that help drive the efficiency and effectiveness of the operation. The most important program component is the people within the organization – without appropriate staffing, a maintenance program cannot reach its maximum potential (Brown, 1996). Since many preventable equipment failures result from craftsmen not understanding basic maintenance procedures, an efficient maintenance program relies on establishing a certain level of job knowledge and task proficiency (Smith, 2000). Although hiring practices can play a role in ensuring the quality of workers, an organization must routinely provide training to enhance the skills of both maintenance craftsmen and management (Office of the Legistlative Auditor, 2000; Brown, 1996).

In all but the smallest maintenance operations, the second most important program component is an efficient information management system (Vanier, 2001). In recent years, most maintenance organizations have turned towards a computer-based maintenance management system (CMMS) to handle the large amount of data involved in a maintenance program. A properly implemented CMMS can assist with work scheduling, optimization, and recordkeeping; it also provides a structured framework to aid management decisions (Vanier, 2001; Office of the Legistlative Auditor, 2000; Brown, 1999).

Some additional program components and tools that can contribute to the success of a maintenance program include a maintenance and accountability program for tools and

equipment, a satisfactory parts inventory, an efficient material acquisition process, and an accurate database of technical drawings (Turner, 2002; Lammers, 2002). Each of these components is intended to eliminate situations that could prevent maintenance work from being performed as scheduled. In order to minimize these situations, which are also known as roadblocks, managers should develop new processes or incorporate new tools as necessary (Lammers, 2002). Routine evaluation and revision of the program components is critical to achieving maximum performance from the maintenance program.

*Metrics*

Metrics are numerical indicators that gauge the operational performance of the maintenance organization. If the metrics measure the appropriate values, they can be a very valuable management tool (Hiatt, 2003). Indications of poor performance can drive increases in worker performance, changes to the maintenance strategy, or justification for additional resources, while indications of good performance can identify best practices or outstanding achievement by the craftsmen. Although they may require extensive data collection, metrics are a simple way to help management make appropriate decisions to optimize the effectiveness and efficiency of maintenance operations (Berger, 2004).

Creative managers can develop metrics to gauge just about any imaginable aspect of maintenance; however, there are three common categories of metrics that apply to maintenance operations: overview indicators, routine maintenance indicators, and equipment performance indicators (Hiatt, 2003). Overview indicators measure the performance of the maintenance organization from an external perspective; they look at such aspects as budget control and regulatory compliance (Hiatt, 2003). Routine maintenance indicators measure the performance

of the maintenance organization in terms of schedule compliance and productivity; these metrics gauge aspects like average completion time per work order and the number of uncompleted work orders (Hiatt, 2003). Equipment performance indicators are perhaps the most important metrics because they gauge the effectiveness of the maintenance operation in terms of the impact it has on the equipment; these metrics look at such aspects as average time between failures, equipment downtime due to maintenance, and the number of unplanned equipment failures (Hiatt, 2003; Lin et al., 2002).

While metrics can be very helpful when making decisions, there are a few considerations that managers must take into account. In most organizations, there is a tendency for workers to please their managers; if a boss wants the metrics to improve, data can be easily falsified or "pencil whipped" to boost the numbers (Lammers, 2002). When this occurs, the inaccurate metrics can mask the true performance of the organization and delay needed changes. Managers must also be sure to measure the right metrics because efforts to improve the wrong metrics can lead to unintended results (Hiatt, 2003). In some cases, it can take a few months of data collection before the metrics start to show any trends, so managers should be patient when implementing new metrics (Lammers, 2002). Finally, when metrics reveal adverse trends, managers must take action; otherwise, the metrics will lose their value within the organization (Lammers, 2002).

*Implementation Rules of Thumb*

Developing an effective maintenance strategy can be an overwhelming task for many organizations. When a truly efficient, optimized maintenance program is out of reach, managers are often pleased with just finding simple ways to increase the proportion of planned work over

emergency work (Berger, 2004). Most managers understand that the key to becoming proactive is to develop a thorough and effective preventive maintenance program (Brown, 1999). Through implementation and testing of some simple rules of thumb, managers can make small incremental improvements to their programs which can pay large dividends in the long run.

One category of these simple rules of thumb deals with ensuring that resources are only spent on worthy maintenance activities. Although it is possible to develop preventive maintenance actions which could improve the performance of nearly every element of a facility, it is not always cost effective to do so (Magee, 1988). Unless the risk to safety or mission is too high, preventive maintenance should not be performed on a piece of equipment when the cost to replace the equipment is less than the cost of maintenance. There are no problems with allowing a component to run to failure, as long as it is the most cost effective alternative (Idhammer, 2008). In cases where preventive maintenance actions are continually deferred or ignored on a piece of equipment and there are no negative impacts, the maintenance should be done less often or stopped altogether (Magee, 1988). Similarly, if conditions-based inspections rarely reveal discrepancies, this is also an indicator to reduce the inspection frequency or completely eliminate inspections (Magee, 1988).

A second category of these rules includes tips for refining a preventive maintenance program. Preventive maintenance is specifically defined in theory; however, in practice, a broader application of the term can be advantageous because it prevents fragmentation of the program into separate parts for routine, preventive, predictive, and other maintenance variations (ADEED, 1999). Preventive maintenance is often more cost effective when maintenance actions are primarily conditions-based and predictive in nature; this is especially true for overly intrusive or overhaul-based maintenance actions (Idhammer, 2008; Turner, 2002). While numbers may

vary slightly depending on the source, a general rule is that a preventive maintenance program should generate three corrective work orders for every ten inspections performed (Brown, 1999). As suggested above, if the ratio of deficiencies to inspections is less, the frequency of checks should be decreased. One way to improve the efficiency of conditions-based inspections is to use modern diagnostic tools that do not require intrusive inspections or production stops to retrieve relevant data (Turner, 2002).

The final category of rules includes common-sense concepts. Like most business functions, maintenance requires a well balanced approach. Regardless of how extensive a particular preventive maintenance program may be, corrective or reactive maintenance can never be ignored (Sheu & Krajewski, 1994). Emergency equipment failures can occur at any time, and the overall performance of the maintenance organization will rely on its ability to respond appropriately. In order to realize the full potential of an asset, it should be operated and maintained according to its intended purpose and design (Quan et al., 2007). Deviations can result in substandard equipment performance. A final important rule, which was repeated throughout the literature review, is to perform periodic assessments of a maintenance strategy (Turner, 2002; Magee, 1988). Organizational goals, maintenance priorities, equipment impacts, and available technologies constantly evolve; as such, periodic re-evaluation of a program will guarantee that the maintenance program and its processes are updated as necessary to ensure maximum benefit to the organization.

### *Change Implementation*

Implementing any type of organizational change can be a difficult process, and results can be negligible if certain fundamental concepts are ignored. Altering a maintenance strategy is

one type of organizational change that can be particularly challenging. Organizations can improve their chances of successfully modifying their maintenance strategy by following guidelines for change implementation.

Prior to implementing change, managers must thoroughly examine whether a problem truly exists, and if so, why it exists (Smith, 2000). Managers must consider any and all potential sources of the problem, such as craftsman skills, organizational culture, management support, program components, and so forth (Smith, 2000). Once the potential sources of a problem have been identified, the manager must then determine all management flaws or fundamental process errors that contributed to the problem (Mahoney & Nguyen, 2003). Armed with a thorough understanding of the problem, the manager can begin planning and identifying alternative solutions. When deciding between alternatives, managers should utilize all decision tools at their disposal to choose the best solution to the problem and set the vision for the maintenance organization (Mahoney & Nguyen, 2003). This approach provides managers with a framework for determining appropriate changes and establishes an essential foundation to justify changes.

When implementing change, management must provide direction and encourage organizational support by being fully committed to the new methods; otherwise, the effort will lose momentum and potentially die away (Smith, 2000). Many people are resistant to change because they fear it, but these fears are often caused by a lack of understanding (Hiatt, 2003). Therefore, management must convey the importance of the changes and provide an action plan that fully explains how the effort will produce the desired results (Smith, 2000). Additionally, management must make an effort to change the organizational culture and processes simultaneously; failure to effectively change both aspects often results in an organization reverting to previous methods (Hiatt, 2003). Finally, continuous improvement is critical to

successful change – managers must actively evaluate changes early and often to identify necessary alterations to ensure the desired effect is achieved (Mahoney & Nguyen, 2003).

### Summary

This literature review provided a thorough analysis of relevant information pertaining to modernizing a preventive maintenance strategy for facilities and infrastructure. Six primary topics were discussed: maintenance management, the four most common maintenance strategies, maintenance optimization models, decision modeling and analysis, asset management, and comparison of applied maintenance practices. A thorough understanding of the information discussed in this literature review serves as a valuable foundation from which to conduct an evaluation and modernization of a preventive maintenance strategy.

# 3. Methodology

This chapter provides an explanation of the methodology used to achieve the objectives of this thesis study, and it consists of two distinct phases. The purpose of the first phase was to develop an understanding of the gap between the program and what it needs to become; it has two segments: data collection and analysis. The data collection section of this chapter provides an explanation of the data collection objectives, what information will be collected and why, collection methods, Institutional Review Board (IRB) exemption, and all other factors pertaining to the gathering of information for this study. Information gathered during the literature review and data collection was synthesized in the analysis segment using a strengths, weaknesses, opportunities, and threats (SWOT) analysis. This section of the methodology chapter provides an explanation of SWOT applications and features, as well as the process used to implement the SWOT analysis for this thesis. Building upon the results of the first phase, the purpose of the second phase was to develop a solution to bridge the previously identified gap. The model development section of this chapter provides an explanation of the model building approach and refinement process. Figure 5 represents the methodology used in this study; the diagram graphically demonstrates how the different portions of the methodology relate as described throughout this chapter.

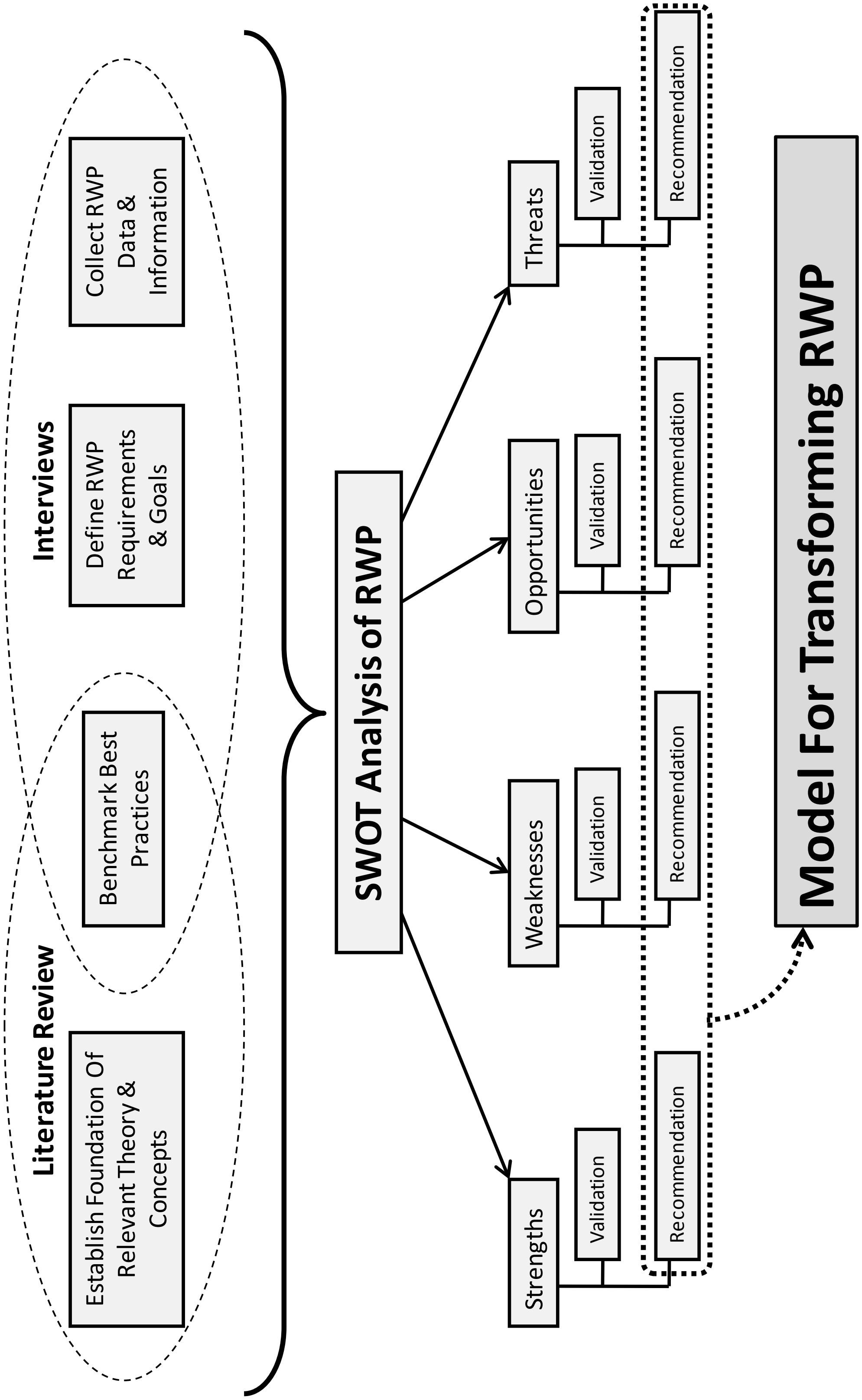


Figure 5. Methodology Process Diagram

**Data Collection**

There were two primary objectives of the data collection effort – (1) to develop an understanding of the existing Recurring Work Program (RWP) and (2) to determine how the RWP needs to change. This information was gathered through interviews with individuals in the Air Force Civil Engineer community who have extensive experience with the RWP. In order to meet the first objective, subjects were asked to share their thoughts on the current program and their experiences with it over their careers; specific areas of interest included positive and negative attributes, pitfalls, and best practices. For the second objective, subjects were asked about their opinions on the desired outcomes of a properly implemented RWP and criteria on which to gauge the performance of a transformed RWP.

Due to the fact that collecting data via interviews required interaction with human subjects, evaluation by an Institutional Review Board (IRB) was required before data collection could begin. The purpose of the IRB was to ensure that either: (1) there are no adverse impacts to the subjects or (2) any adverse impacts are justified and minimized. Due to the negligible possibility of this study adversely impacting subjects, it qualified for IRB exempt status on the condition that certain provisions were met and upheld. These provisions, intended to protect subjects and their privacy rights, included: subject participation must be strictly voluntary, no adverse action will be taken against those who choose not to participate, no names will be associated with reported data, and subjects must be fully informed of the purpose of the research and how their input will be used.

Subjects were initially selected based on references from senior members of the Air Force Civil Engineer community who belong to the various Major Command (MAJCOM) Civil Engineer Operations (A7O) divisions. In order to develop a broad understanding of the program from various perspectives, interview candidates were identified from a mixture of backgrounds.

For additional insight, interviews were also solicited from former members of the Civil Engineer community who now work in private-sector and non-military, public-sector maintenance organizations; having personal experience with both organizations, these members could provide a unique comparative perspective between RWP and equivalent programs outside the Air Force.

In total, 25 interviews were conducted for this study. The interview subjects included civilians, senior non-commissioned officers, and officers from the Air Force Civil Engineer career field with an average of approximately 22 years of experience in the career field. Subjects had a wide variety of perspectives, having held various past and present positions with respect to the RWP, to include: Craftsman, Shop Chief, Element Superintendent, Chief of Maintenance Engineering, Operations Flight Superintendent, Deputy Operations Flight Chief, Operations Flight Chief, Squadron Commander, Mission Support Group Commander, Major Command (MAJCOM) Operations Branch (A7O) Staff, and A7O Director. At the time of the interviews, subjects also represented a wide variety of MAJCOMs, to include: Air Combat Command (ACC), Air Education and Training Command (AETC), Air Force District of Washington (AFDW), Air Force Materiel Command (AFMC), Air Force Special Operations Command (AFSOC), Air Force Space Command (AFSPC), and Air Mobility Command (AMC). Furthermore, all MAJCOMs had been home to one or more interview subjects throughout their careers, and most subjects had served under multiple MAJCOMs.

There were two methods of personal interviews conducted for this study. The first method consisted of in-person and phone interviews. Each interview was recorded and transcripts were developed, then each transcript was summarized and edited from conversational form to written form. Each subject was given the opportunity to review the final version and ensure there were no errors in translation. This type of interview was deemed complete once

each subject had the opportunity to review and approve the final summarized version of his or her interview. The second method consisted of self-paced electronic interviews conducted via e-mail. Subjects were provided five to six open-ended questions and given an unlimited amount of time to respond. Each subject's initial questions were based on his or her rank and current position, and based on the responses additional follow-up questions were asked and answered, also via e-mail. This type of interview was deemed complete once all follow-up questions were answered by the subjects. A sample of the interview questions includes:

- In your opinion, is/was RWP worthwhile? Explain.
- What are the particular strengths and weaknesses of the current RWP?
- Have you experienced or witnessed any particularly effective RWP practices? Explain.
- Have you experienced or witnessed any particularly ineffective RWP practices? Explain.
- In your opinion, should the current RWP be changed? Explain.
- What can or should be done to improve RWP?

By no means is this list all-inclusive; these questions are simply meant to serve as a representative sample.

Once all interviews were complete, the interview responses were transferred to a database and organized by question. Each response was edited to remove any information that could possibly be used to identify the interview subject; this information included personal names, unit names, base names, specific years or dates, and awards received. At the conclusion of the data analysis, the personal interviews associated with an individual subject were destroyed. To

further protect the identity of subjects, response order within the database was randomized. The final database of responses, organized by interview question, is provided in Appendix B.

## Analysis

Once the data was collected, the second segment of the first phase of the methodology consisted of data analysis. The objective of the data analysis was to evaluate relevant literature and all collected data in order to develop an understanding of the gap between the current RWP and what it should become. A Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis was the primary method of evaluation; SWOT analysis is a widely used, well-balanced approach for improving organizational performance and developing strategic plans (Wiig, de Hoog & Van der Spek, 1997; Karppi, Kokkonen & Lahteenmaki-Smith, 2001). There are three significant steps for completing a SWOT analysis: identification of findings, classification and validation for each finding, and recommendation of a course of action for each finding (Balamuralikrishna & Dugger, 1995).

The SWOT analysis was chosen as the analysis method in this study because of its straightforward approach, flexibility, and practical/useful output (Houben, Lenie & Vanhoof, 1999; Balamuralikrishna & Dugger, 1995). By definition, SWOT consists of specifying a business objective and identifying all internal and external factors that are favorable or unfavorable to achieving the objective (Balamuralikrishna & Dugger, 1995; Houben et al., 1999). Definitions for each of the four SWOT factor classifications are established by pairing each of the two possible sources (internal/external) with each of the two possible impacts (helpful/harmful). The resulting definitions are shown in Figure 6, which helps illustrate the relationship between each of the SWOT factor classifications.

| | Helpful | Harmful |
|---|---|---|
| Internal Origin | Strengths: attributes of the organization that are helpful to achieving the objective | Weaknesses: attributes of the organization that are harmful to achieving the objective |
| External Origin | Opportunities: external conditions that are helpful to achieving the objective | Threats: external conditions that are harmful to achieving the objective |

Figure 6. SWOT Factor Classification Diagram

The first step in performing a SWOT analysis is to clearly identify the overarching objective of the analysis (Wiig et al., 1997). With the objective in mind, the next step is to review all relevant information and identify any significant factors that could be classified as strengths, weaknesses, opportunities, or threats with respect to achieving the objectives – these are also known as “findings.” As a rule of thumb, the researcher should ensure that each finding is sub-divided to the lowest possible level because findings with multiple attributes can make classification difficult (Wiig et al., 1997). Additionally, due to the interrelatedness of some factors, the researcher must clearly delineate between internal and external findings because failure to do so can cause problems in further sections of the SWOT analysis (Karppi et al., 2001; Houben et al., 1999). Once the findings have been identified and classified, the next step

of the SWOT analysis is to validate each finding by citing all supporting information used to determine the classification, to include: relevant theory and concepts, industry standards, best practices, and information provided in the data collection.  Thorough validation adds credibility to the final results of the SWOT and provides a smooth transition to the next step of the analysis.

The final step of the SWOT analysis is to recommend a course of action for each finding. During this stage, it is critical for the researcher to consider multiple viewpoints in order to make recommendations that benefit all parties involved (Balamuralikrishna & Dugger, 1995). Common recommendations for strengths include continuing the current course of action and various ideas to build on positive effects of the strength (Karppi et al., 2001).  For weaknesses, common recommendations include halting the current course of action and various ideas to minimize or eliminate negative effects of the weakness (Karppi et al., 2001).  In the case of opportunities, recommendations are geared toward identifying ways to take advantage of the situation to benefit the objective.  For threats, on the other hand, recommendations are aimed at protecting the objective from potentially negative impacts.  As in the validation phase, a thorough use of supporting information for each recommendation will lend overall credibility to the SWOT analysis.

## Model Development

Building upon the foundation provided by the data collection and analysis efforts, the final phase of the methodology was development of a model that provides practical guidance to bridge the gap between the current RWP and what it needs to become.  The model consisted of a series of focus areas (FAs), each of which is a unique theme of practical recommendations for

improving the program. Each FA was developed by compiling, de-conflicting, strengthening, and filling any gaps between the recommendations from the SWOT analysis.

The model consisting of the FAs provides a comprehensive approach to modernize the RWP that a simple summary of the recommendations from the SWOT cannot adequately provide. To support the ideas suggested in the focus areas and to enhance the potential applicability of the final model, a series of implementation concepts were developed. These concepts are not intended to be strict instructions for applying the model; rather, they are simply suggestions for possible ways to put the FAs into action, and they provide a starting point from which to practically implement the model. Each implementation concept was discussed in the applicable focus areas and included as an appendix to this thesis.

**Summary**

The objective of this study was to develop a model for evaluating and modernizing a preventive maintenance strategy using the Air Force RWP as a case study. Developing an understanding of the gap between the program and what it needs to become was the objective of the first phase, and it included data collection and SWOT analysis. Developing a solution to bridge the previously identified gap was the objective of the second phase; it included building a model for modernizing the program. Collectively, the two phases of the methodology provide a structured framework to meet the study objective.

# 4. Results and Discussion

## Introduction

This chapter provides an explanation of the analysis and model development results from this thesis; it is organized into two main sections. The first section is an overview of the results of the strengths, weaknesses, opportunities, and threats (SWOT) analysis. For each finding, a short discussion is provided to explain how the finding was identified and classified. The second section is a discussion of the model developed for modernizing the Recurring Work Program (RWP), which consists of eight focus areas. A detailed explanation, recommendation for further action, and discussion of applicable implementation concepts are provided for each.

## Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis

The desired outcome of this SWOT analysis was to determine the gap between the current RWP and what it needs to become. Findings were identified from common themes in the interviews and gaps between the current program and best practices in industry. Once identified, each finding was classified according to its potential impact on modernizing the RWP. In addition to the traditional four classifications, a fifth classification, "Unclassified Finding," was created to capture those findings that could meet the conditions of different classifications depending on the context of the evaluation. Figure 7 displays all of the findings from the SWOT analysis, organized by classification. In the following pages, a short discussion is provided to offer an explanation about how/why each finding was identified and classified. As discussed in the methodology, a recommendation for further action was developed for each finding. Since these were used to develop the focus areas, these recommendations will be discussed in the applicable focus areas in order to minimize redundancies in the discussion.

| | Positive Impact | Negative Impact |
|---|---|---|
| **Internally Controlled** | **Strengths**<br>**S1.** The basic concept/intent of the program and the basic instructions (as outlined in the current references), if implemented properly, can produce a very cost effective and efficient maintenance program | **Weaknesses**<br>**W1.** Actual performance data for RWP actions is not being collected/tracked accurately<br>**W2.** Annual reviews of the RWP are not being completed<br>**W3**. Maintenance Actions Sheets are not being adequately developed and/or updated<br>**W4.** The metrics used to gauge RWP are encouraging poor practices<br>**W5.** Leadership attention to and accountability within the RWP are lacking<br>**W6.** Education about how to implement a RWP and the benefits of an RWP are lacking |
| **External To Program** | **Opportunities**<br>**O1.** Develop a risk/cost-based decision framework to assist with reviewing the RWP<br>**O2.** Capitalize on advances in computer-based maintenance management technology<br>**O3.** Implement predictive (conditions-based) maintenance practices and technology<br>**O4.** Establish and disseminate organization-wide standardized approaches to RWP<br>**O5.** Establish and utilize communities of practice to share RWP information<br>**O6.** Develop and utilize a service contract 'Surge Capability'<br>**O7.** Encourage multi-craft coordination for RWP activities<br>**O8.** Utilize RWP to sustain equipment warranties | **Threats**<br>**T1.** The RWP is just one of many priorities competing for limited resources<br>**T2.** The RWP has a poor image that may hinder improvements to the program<br>**T3.** Craftsmen and engineers are functionally separated within the CE unit<br>**T4.** New Operations Flight Chiefs have very little or no prior experience in operations<br>**T5.** RWP is rarely adjusted to meet changes in available manpower<br>**T6.** RWP is used incorrectly<br>**T7.** RWP decisions do not always consider the whole system perspective |

| | |
|---|---|
| **Unclassified** | **Unclassified**<br>**U1.** Utilize energy savings potential to measure and adjust the RWP<br>**U2.** Delegate minor RWP tasks to facility managers<br>**U3.** Extend completion suspense for urgent and routine Direct Scheduled Work |

Figure 7. RWP SWOT Analysis Results

*Strengths*

Strengths are defined as elements or characteristics of the current program that either positively affect or do not detract from the desired outcome (Karppi et al., 2001). Maintaining or increasing the current emphasis on a program's strengths would positively contribute to the desired outcome. This SWOT analysis only identified one strength of the current RWP.

- <u>S1. The basic concept, intent, and instructions for the RWP (as outlined in current references), if implemented properly, can produce a very productive/effective program.</u>

Almost all interview subjects stated that RWP is a worthwhile program that can have good results if it is implemented properly, and many of the interviewees have been personally involved with very successful RWPs in past assignments. These successful RWPs followed the basic instructions for the program, to include but not limited to: accurately tracking work data, thoroughly reviewing the program on an annual basis, consistently updating the equipment inventory, utilizing industry standards for developing maintenance actions, prioritizing equipment for maintenance, and advocating for leadership support of the program. Nearly all references to unsuccessful RWPs mentioned that one or more of the basic instructions for the program had not been followed. The basic framework for RWP is sound; it has produced effective results when it has been utilized. Individuals who downplay the importance or capability of the program have likely failed to properly implement the program.

*Weaknesses*

Weaknesses are defined as elements or characteristics of the current program that either negatively affect or detract from the desired outcome (Karppi et al., 2001). Removal or

alteration of a weakness would positively contribute to the desired outcome. This SWOT analysis identified six weaknesses of the RWP.

- W1. Performance data for RWP maintenance actions is not being recorded accurately.

The practice of 'pencil-whipping' work completion data was mentioned in most of the interviews as a major problem with the current program. This term refers to recording inaccurate data for work completion; it is done by charging an incorrect number of labor hours to a work requirement. There are a number of potential reasons why personnel might choose to inaccurately report work completion data; some of the reasons suggested during the interviews included: (1) it requires a lot less effort than accurate data tracking, (2) the shops are trying to meet metrics that gauge the balance between estimated labor requirements and the actual labor charged to a given work category, (3) personnel do not understand how to log accurate data in the Integrated Work Information Management System (IWIMS – the Air Force Civil Engineer computer-based information management system), and (4) personnel do not understand the importance of accurate data tracking. Accurate data is critical because it provides a representation of the amount of work a shop can realistically complete with the manpower and resources it has available. Many personnel simply do not understand the importance of accurate data tracking so they choose to not do it; similarly, many supervisors do not understand the importance of accurate data tracking and do not enforce it. When shops inaccurately report data, they are falsely representing their actual capabilities and showing that they can accomplish all work with their given amount of resources. In a resource-constrained environment and/or in an attempt to maximize the cost effectiveness of a program, leadership often removes resources from a program until a noticeable drop in performance is observed. Inaccurate reporting does

not show a drop a performance; therefore, it can result in resource cuts. Furthermore, it constitutes falsification of an official document.

- W2. Annual reviews of the RWP are not being completed.

One of the basic tenets of RWP is an annual review of the program; however, most interviewees mentioned that these reviews are not being completed. The purpose of the annual review is to update the program to reflect changing conditions (e.g., new or eliminated equipment or facilities), improve the cost effectiveness or risk avoidance of the program, and right-size the program for the available manpower or resources. Units are continually adding RWP actions to the database as new equipment is installed; however, without reviews, the old equipment and old maintenance actions are not being cleaned out of the system. Failure to review the RWP will lead to a very inefficient and ineffective program. These reviews may not be completed for various reasons; some of the reasons suggested in the interviews included: (1) it takes a lot of man-hours and effort that the shops do not have, (2) accurate data has not been tracked to support a review, (3) shops lack the tools or expertise to complete a review, and/or (4) personnel (shops and leadership) do not understand the importance of the reviews. If a RWP is not producing results, the annual review is the best opportunity for management to optimize, prioritize, and size the program to make it work for them.

- W3. Maintenance Actions Sheets are not being adequately developed and/or updated.

Air Force Forms 1841, Maintenance Action Sheets (MASs), are the heart of RWP. These forms include all the instructions for performing RWP on a given system or piece of equipment, to include the frequency, scope, required materials, and time/labor estimates. When developing

a MAS, one should utilize industry standards, manufacturer's recommendations, regulatory requirements, and other such sources. These same sources should be referenced when updating and reviewing a MAS. While these sources are used in most situations, some personnel develop and review a MAS using their personal judgment, by copying the MAS from other equipment, or using other less-substantiated means. Using a single MAS for multiple pieces of equipment is encouraged because it can save paperwork and extra effort; however, this should only be done when the equipment has identical needs and operating conditions (environment, operating frequency, facility mission, etc.). Interviewees suggested the following problems with the MASs: questionable means are being utilized to develop the MAS, craftsmen are not following the MAS when executing RWP maintenance actions, and craftsmen are not updating the MAS when they identify problems or inadequacies.

- <u>W4. The metrics used to gauge RWP are encouraging poor implementation practices.</u>

The current standard metric to gauge RWP performance compares the number of hours scheduled for RWP to the number of actual hours spent on RWP. Interviewees suggested that this metric encourages two bad behaviors: (1) the shops schedule excessive RWP to provide flexibility in the schedule and (2) the shops 'pencil-whip' the completed maintenance hours in order to match the scheduled hours regardless of what was actually performed. While this metric alludes to a shop’s ability to make and follow a schedule, it does not tell anything about the efficiency or effectiveness of the actual RWP. Using this metric to gauge the success of RWP is detrimental to the overall program and can negatively affect the entire maintenance operation.

- W5. Leadership attention to and accountability within the RWP are lacking.

Many interviewees cited a lack of leadership attention towards the RWP as a major problem with the program. RWP usually only comes to the attention of commanders when either (1) a facility or system begins to have recurring maintenance problems or (2) there is a mission-impacting emergency failure which could have been prevented through RWP. Due to the lack of leadership attention to this program, RWP is not considered a priority and does not receive the support and emphasis it requires to be effective. Common problems cited in the interviews included: leaders do not provide adequate time or resources to the program, leaders claim RWP is a top priority but take time or resources away from RWP to meet other requirements (e.g., planting flowers or painting grass for special events, picking up trash, etc.), leaders do not enforce or encourage accurate data recording, leaders do not encourage or check the accuracy of work scheduling, and leaders do not enforce or provide time for annual reviews of the program. "Leaders" in this sense refers to all members in the chain of command, from shop chiefs to the wing commanders – essentially anyone who has the ability to make decisions about where and how manpower is being used.

- W6. Education about how to implement a RWP and the benefits of the program are lacking.

A general lack of education, training, and knowledge about the RWP from all levels of involvement in the program was repeatedly mentioned throughout the interviews. There is a lack of understanding in both the importance of the program and how to implement it. Most people understand the concept and value of preventive maintenance in terms of their vehicles (e.g., oil change every 3000 miles), but very few people relate it to the facilities and infrastructure on a military installation. Unfortunately, there are very few sources or opportunities for Civil

Engineers to learn about the program; similarly, there are few personnel across the Air Force who have the requisite knowledge to properly instruct others about the program. The most recent official publications that reference RWP are over 10 years old, and formal training classes for both enlisted members and officers only touch on RWP briefly, if at all.

*Opportunities*

Opportunities are defined as elements or characteristics that are outside the control of the organization or program, or which could be added to the program to positively affect the desired outcome (Karppi et al., 2001). Altering the current program to take advantage of an opportunity would positively contribute to the desired outcome. This SWOT analysis identified eight opportunities for the RWP.

- <u>O1. Develop a risk/cost-based decision framework to assist with reviewing the RWP.</u>

In many situations, RWP is the first type of work to get cut from a schedule in light of more tangible, real-time emergencies and requirements. Unfortunately, these decisions are often made with no consideration of potential long-term cost or mission impacts. Leaders should make informed decisions about how and where to allocate their resources, and a risk/cost-based decision framework for RWP could provide the appropriate information to make informed decisions about whether or not to perform RPW on a given equipment item or system. This framework could also be used to prioritize equipment within the RWP in order to assist leaders when balancing available resources and determining where to draw the line between what can feasibly be maintained and what cannot be maintained. Furthermore, this decision tool could

provide supporting evidence to use when educating about the benefits of the program and when advocating for program support.

- <u>O2. Capitalize on advances in computer-based maintenance management technology.</u>

The current computer-based maintenance management system (CMMS) for Air Force Civil Engineers, IWIMS, has been around since the early 1980s. Computer systems have advanced considerably over the last ~25 years, and the capabilities of computer-based maintenance management systems have improved drastically. IWIMS is out-dated, and it is not particularly user-friendly. Using the current generation of computer technology, a commercially available CMMS product could meet or could be further developed to meet Air Force needs.

- <u>O3. Implement predictive (conditions-based) maintenance practices and technology.</u>

Preventive maintenance is a wonderful way to prolong the life of equipment and reduce the potential for equipment failure, but it is sometimes not the most cost or resource effective maintenance process due to the fact that certain parts are replaced or certain procedures are performed regardless of the condition of the equipment. Predictive maintenance consists of routine simple inspections to determine the need for maintenance procedures and part replacements. Actions are performed only when needed, and as a result, conditions-based maintenance generally consumes less maintenance resources over the life of the equipment. Interview responses suggested that sometime in the last few years, there was a push within the CE community to begin using predictive maintenance concepts in RWP. Although this initiative is no longer active, some installations have made efforts to utilize predictive methods. Advances in technology, to include remote sensors, controls, and observation equipment, have been used to

make predictive maintenance even more efficient.  When remote sensing equipment is utilized, routine inspections are no longer needed; instead, the equipment notifies the craftsmen when maintenance is required.

- O4.  Establish and disseminate Air Force-wide standardized approaches to RWP.

Large public and private organizations across the world are experiencing great results by approaching their facility and infrastructure programs from an asset management perspective. An asset management perspective considers facilities and infrastructure over an entire lifecycle at the enterprise level of the organization; one of the primary benefits is economies of scale gained by centralized decision making and standardization.  The Air Force CE community is in the early stages of applying an asset management approach throughout its operations, but there is currently wide variation in the RWPs between individual bases.  This variation makes evaluation and comparison between units' programs difficult for MAJCOMs.  Since the RWP is a program that should be adjusted to meet the specific needs of each unit, some variation should be expected due to differences in environmental conditions, resource availability, mission, leadership, etc.  However, there are some aspects of the RWP that could be standardized across the Air Force to help minimize the guess work and man-hours involved with developing, reviewing, and evaluating an RWP.

- O5.  Establish and utilize communities of practice to share RWP information.

A Community of Practice (CoP) is an opportunity for individuals with a common purpose to interact, share ideas, and build upon each other's knowledge.  Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it

better as they interact regularly (Wenger, 2004). CoPs can take place in a variety of formats, to include personal meetings, teleconferences, and web-based forums. The Air Force Knowledge Now (AFKN) website is a CoP platform that already exists specifically for Air Force users, and there is a Civil Engineer Operations Support CoP on the AFKN website. This CoP was established for members of the CE Operations Support Community to share knowledge about programs like the RWP. If used as intended, this CoP could be a great way for units to share ideas and learn best practices for creating, updating, and implementing the RWP. Unfortunately, participation within this CoP is minimal, so the benefit of this potentially useful tool is limited.

- O6. Develop and utilize a service contract "Surge Capability."

Two of the interview subjects recommended establishing a service contract mechanism to provide skilled labor to assist with tackling severe back-logs of RWP maintenance requirements. In their experience, this "surge" capability was very helpful in either accomplishing delinquent work requirements during particularly busy times or compensating for missing manpower during deployment cycles. Although there is certainly a cost associated with providing the surge capability, the potential benefits of staying on top of requirements may outweigh the costs of providing the capability.

- O7. Encourage multi-craft coordination for RWP activities.

Multi-craft coordination was mentioned numerous times throughout the interviews as a best practice for RWP; there were two general forms of multi-craft coordination that were identified. The first concerns individual systems with components that require recurring maintenance actions from various crafts. An example of this type is fire suppression systems

which require coordination between alarms and utilities personnel. Since system and/or facility downtime is required for each craft to perform their RWP requirements, coordination between the crafts can minimize the amount of overall system and/or facility downtime and help make the recurring maintenance more efficient. The second form of multi-craft coordination for RWP is a facility inspection team. These teams were called various names in the interviews (SMART teams, Tiger teams, etc.), but the basic concept is the same: a team of craftsmen from various shops visits a facility or mechanical room to perform a slate of inspections, basic recurring maintenance, cleaning, and records updating activities. These teams can be particularly effective for creating a baseline from which to revamp or restart an out-dated RWP.

- O8. Utilize RWP to sustain equipment warranties.

Many of the equipment items and systems purchased and installed by Civil Engineers have manufacturers' warranties that guarantee performance for a given time period. However, most of these warranties depend on the units performing certain recurring maintenance requirements; if these requirements are not met, the warranties may become void. RWP actions can be developed to track and ensure implementation of the warranty-based maintenance, which can help units take advantage of the warranty conditions and opportunities to fix or replace faulty equipment at no charge.

*Threats*

Threats are defined as elements that are outside the control of the organization or specific program which could negatively affect the desired outcome (Karppi et al., 2001). Altering the

current program to avoid threats or mitigate their effects would positively contribute to the desired outcome.  This SWOT analysis identified seven threats to the RWP.

- <u>T1.  The RWP is just one of many priorities competing for limited resources.</u>

The Air Force is currently fighting an on-going war on terror, attempting to replace aging aircraft, and meeting numerous other requirements, all while facing a shrinking budget.  At the same time, threats to the nation's safety and security continue to rise, and the Air Force must still be prepared to meet every challenge.  The benefits of performing routine maintenance are often difficult to visualize, so commanders are often more likely to spend resources on more tangible problems and programs.  As stated in one of the interviews, "customers don't ask for RWP," so devoting resources to the program can sometimes be hard to justify.  In light of these various concerns, the RWP runs a severe risk of not receiving the appropriate level of support it requires to produce effective results.

- <u>T2.  The RWP has a poor image that may hinder improvements to the program.</u>

Many people within the CE community consider the RWP to be a program that is designed to control them, rather than a program that can help them control the balance between their resources and infrastructure.  Since the RWP has been poorly implemented in many ways for many years, examples of properly implemented and productive RWPs are limited.  Many CE units consider the RWP to be something that is “done just because it’s always been done,” and they grudgingly comply with the program but fail to update it or accurately track it because they see no value in the program.  If personnel fail to utilize the program properly, they will never see or understand the potential benefits of the program.

- T3.  Craftsmen and engineers are functionally separated within the CE unit.

In the early 1990s, the Air Force CE community developed the Maintenance Engineering element with the intent of bringing degreed engineers in close contact with craftsmen from the various shops within the Operations Flight.  In concept, the two groups could benefit from each other's expertise to enhance the efficiency of various facility and infrastructure programs.  Since its inception, Maintenance Engineering has been responsible for the oversight and review of the RWP; however, many interviewees suggested that in most cases Maintenance Engineering has failed to adequately perform this function.  Two of the major reasons cited include (1) a general lack of communication between the craftsmen and the engineers and (2) the fact that Maintenance Engineering became a catch-all for various operations support programs and was never adequately staffed to accomplish everything it was assigned.  Most of the interviewees suggested the shops were able to adequately conduct the RWP alone with no assistance from Maintenance Engineering.  Due to an Air Force-wide CE squadron re-organization, Maintenance Engineering has relocated from the Operations Flight and moved into the newly formed Programs Flight.  This move has further separated the craftsmen and the engineers, thereby decreasing the chance that the two groups can work together.

- T4.  Operations Flight Chiefs have very little or no prior experience in the Operations Flight.

For many CE officers, the first chance of working in the Operations Flight is when they get the opportunity to be the flight chief.  Although many company grade officers had the chance to work in Maintenance Engineering in the past, this element has transitioned to the Programs Flight and is no longer an opportunity to gain Operations Flight experience.  Even so, Maintenance Engineering gave officers minimal opportunities to learn basic Operations Flight

leadership functions like work order management and weekly scheduling. As a result, some Operations Flight Chiefs may not understand how to properly implement and enforce the RWP.

- T5. RWP is rarely adjusted to meet changes in available manpower.

During deployment cycles, a unit's available manpower can drop to as low as 50% of normal levels depending on the respective number of military and civilian positions in the unit. Although additional manpower can temporarily be hired to partially fill the void, the decrease in manpower will inevitably cause a decrease in the amount of work that can realistically be accomplished. If the decrease in manpower results in RWP actions being skipped or deferred, shops must appropriately adjust the program. Furthermore, when passing on RWP actions, shops must ensure that the least cost-effective or risk-averse actions are the first to be skipped or deferred. Similarly, as manpower increases (e.g., when personnel return from a deployment), shops should re-adjust the RWP again to meet the amount of available manpower. If an RWP is not adjusted to address changes in manpower, and if records indicate no changes in performance of RWP, the units are either pencil-whipping data or showing that they do not need the personnel who are missing from the normal manpower level.

- T6. RWP is used incorrectly.

The RWP should only be used for those equipment or systems that require or can benefit from time-based recurring maintenance activities. The program is not designed for any type of activity that occurs randomly; however, interview responses suggested that RWP has been incorrectly used to manage some of this type of work. An example of an inappropriate activity for which RWP has been used is snow removal. Since snow is a natural phenomenon that does

not occur according to a set schedule, it is not practical to establish a recurring maintenance action for snow removal. Using RWP to manage inappropriate activities severely discredits the program and contributes to its poor image.

- T7. RWP decisions do not always consider the whole system perspective.

Over the years, many different standards have been established to help units identify which equipment should and should not be maintained via RWP. These standards are usually based on cost or risk considerations; while they can be very helpful, they can also be potentially misleading by directing attention away from the whole system perspective. For example, one of the past standards identified by one interview subject was, "Do not perform RWP on any item that has a replacement value less than $500." While this standard may have been effective for some stand-alone equipment, it was not appropriate for equipment items whose failure could cause the indirect failure of larger, more expensive systems to which the equipment item belonged. As this example shows, failure to consider the whole system perspective when deciding whether or not to perform RWP on an individual equipment item can threaten the potential effectiveness of the RWP.

*Unclassified Findings*

Unclassified findings were those that did not necessarily fall into a particular classification but were worthy of discussion because they were mentioned a handful of times throughout the interviews. Each of the unclassified findings has both positive and negative aspects that depend on the context in which they are examined. This SWOT analysis identified three unclassified findings for the RWP.

- U1.  Utilize energy savings potential to measure and adjust the RWP.

In most circumstances, equipment that is maintained in prime condition will operate more efficiently than equipment that is not; by keeping equipment in prime operating condition, RWP could be one way to decrease energy consumption.  The idea of emphasizing RWP from the energy savings potential was mentioned in many of the interviews due to the current Air Force emphasis on energy conservation.   Although energy savings is another one of many potential benefits of RWP, the additional effort required to estimate and calculate the energy savings from RWP could be substantial.  Furthermore, RWP should already be prioritized according to risk and cost effectiveness; adding another dimension for prioritization could make implementation of the program more difficult.  Focusing on energy savings is considered an unclassified finding because it could be both an opportunity for the program (in terms of improving energy efficiency) and a threat to the program (in terms of the additional effort required to incorporate energy data, which could hamper efficient implementation of the program).

- U2.  Delegate minor RWP tasks to facility managers.

Two interview subjects suggested that some simple RWP tasks could be delegated to facility managers.  Although this concept is a potential opportunity in the fact that it would alleviate some simple tasks from CE craftsmen, it could also be a potential threat in the fact that CE has no accountability over the facility managers to enforce completion of these tasks. Furthermore, most facility managers do not have requisite skills to accomplish much beyond simple inspections or monitoring controls – tasks which could be just as easily and more reliably performed by automated equipment.

- U3. Extend completion suspense for urgent and routine Direct Scheduled Work

One interview subject suggested that the current response times for urgent and routine direct scheduled work (DSW) should be increased from their current levels (7 days to 30 days and 30 days to 90 days, respectively). The concept behind this idea is that a decreased emphasis on DSW would permit more emphasis on RWP. The current urgent and routine response times encourage the shops to focus on DSW in order to meet expectations. These times were set when the Air Force was larger and had more available manpower; however, these times are difficult to meet under current manning without overlooking other responsibilities (e.g., RWP). Although this concept could work, it does not consider the potential decrease in customer satisfaction that would result from delaying the response times for urgent and routine DSW.

**Focus Areas**

The following Focus Areas (FAs) were developed by compiling, de-conflicting, and strengthening the individual recommendations from the SWOT analysis. The FAs belong to three categories, which taken together comprise a model for modernizing the RWP and bridging the gaps identified through the SWOT analysis. The first category consists of two aspects of the current RWP which have been severely neglected: accurate recordkeeping and annual program reviews. All of the productive and effective RWPs mentioned in the interviews have focused heavily on both of these functions, whereas an overwhelming majority of ineffective RWPs failed to perform one or both. The second category consists of two aspects that are not necessarily part of the current RWP but are basic concepts stressed throughout maintenance management literature: leadership attention to the program and education and training. While these aspects alone will not create a successful program, they are critical for ensuring that the

program has the necessary tools and support to perform effectively. The third category consists of four concepts/ideas to take the program to the next level of performance: common RWP standards, Integrated Work Information Management System (IWIMS) replacement, predictive maintenance, and redesigned metrics. These concepts take advantage of new technologies and best practices within the maintenance industry to make RWP more practical, less time-consuming, and/or more productive. Although each FA is a unique theme, there is some overlap in the sense that efforts focused towards one FA may positively influence others; likewise, the recommendations for implementing one FA may suggest efforts within the theme of another FA. Table 8 provides a summary of the eight focus areas and the categories to which they belong; it is followed by a discussion of each FA.

| FA # | Title | Category |
|---|---|---|
| 1 | Accurate Recordkeeping | Category 1: Aspects of current program that have been severely neglected; program could be successful as currently designed if these are performed |
| 2 | Annual Program Reviews | |
| 3 | Education and Training | Category 2: Not formal aspects of the current program, but critical concepts for successful maintenance operations and management |
| 4 | Leadership Attention | |
| 5 | Common RWP Standards | Category 3: Not part of the current program; ways to take advantage of new technology and best practices in industry to improve RWP |
| 6 | IWIMS Replacement | |
| 7 | Predictive Maintenance | |
| 8 | Redesigned Metrics | |

Figure 8. RWP Focus Areas

*Focus Area #1: Accurate Recordkeeping*

Accurate records are necessary in order to track operational performance, resource utilization, equipment condition, etc. Failure to keep accurate records can be considered falsification of an official statement, and it produces an inaccurate representation of an organization's capabilities. If an organization cannot complete all their work with the available resources, records must show as such; otherwise, there is no basis for requesting additional resources or adjusting priorities. Furthermore, without accurate records, there is no basis from which to improve or update a program.

There were four findings from the SWOT analysis that supported this focus area: S1, W1, T2, and T5. In order to correct this problem, personnel should be educated on the importance of accurate recordkeeping in terms of scheduling efficiencies and representing true capabilities based on available resources. Personnel should also be trained on how to accurately record work completion data. Leadership must hold personnel accountable for accurate data recording and encourage integrity. Revised metrics could be used to encourage accurate data recording, and a replacement for IWIMS could be created to make it easier to record correct data. Program reviews and updates should be enforced to ensure estimated maintenance requirements are realistic and match the maintenance that is actually being performed on the equipment.

*Focus Area #2: Annual Program Reviews*

Annual reviews are the opportunity for organizations to make the RWP work for them. Examples of potential problems that could be identified and corrected during a program review include: maintenance frequencies that are too high, MAS estimates that do not match reality, equipment that has been removed or installed, and levels of resources that do not match

programmed workloads. Annual reviews are also an opportunity for maintenance managers to optimize and prioritize the program to get the best return on investment. In addition to the annual requirement, programs should be reviewed any time there are large changes to an organization's available manpower. Failure to review a program encourages poor recordkeeping because maintenance actions that are irrelevant or outdated are more likely to be pencil-whipped.

Four findings from the SWOT analysis supported this focus area: S1, W2, T2, and T5. Recommendations for improving this focus area include educating personnel on the importance of annual reviews and training them on how to properly implement an annual review. Leadership should emphasize the importance of the reviews, provide the necessary time and manpower to complete the reviews, and hold personnel accountable for completing them. Accurate data records are critical for providing a basis for changes to the program, and revised metrics could help identify when reviews are approaching overdue status. Program review completion could be emphasized by creating a special annual effort led by the Operations Chief or a unique multi-skilled team. Additionally, MAJCOMs could get involved by tracking compliance of annual RWP review performance.

An additional way for the Air Force to facilitate the completion of annual reviews is to establish standard guidance for performing a review. This standard guidance would enhance the efficiency and reduce the guesswork involved with performing an annual review. To provide a practical example of what this would consist of, the 'RWP Review Guide and Decision Tool Concept' was developed and is shown in Appendix C. This concept provides a step-by-step framework for reviewing an RWP that incorporates both cost and risk considerations. It has two parts – the first is a full program review that helps the user prioritize the RWP actions and adjust the size of the program based on available resources. The second part provides a simple process

for evaluating the RWP candidacy for an individual equipment item that was not included in the annual review. Although the decision tool in its current format is somewhat cumbersome, the instructions clearly outline the underlying logic and decision framework which could be incorporated into the IWIMS replacement. This review guide was developed based on input from the interviews, information gathered during the literature review, and a basic understanding of engineering economics.

*Focus Area #3: Education and Training*

Education and training are necessary to ensure the personnel involved with RWP understand the importance of the program and how to properly implement it. If personnel do not understand the program and do not understand how to properly implement it, the RWP will not produce effective results. Similarly, if the organization's leadership does not understand the importance of the RWP, the program will not receive adequate support.

Numerous findings from the SWOT analysis supported this focus area: S1, W2, W3, W5, W6, O4, O5, O8, T1, T2, T3, T4, T6, T7, U1, and U2. Improved education and training could enhance the strengths and opportunities, help correct or avoid the weaknesses and threats, and explore the possibilities of the unclassified findings. Education and training should be focused at all levels of the organization and should address such topics as: the types of work that do/do not qualify as RWP candidates, creating/developing new RWP actions, considering the whole system impacts of RWP decisions, reviewing/updating an RWP, creating/reviewing weekly schedules, using IWIMS (or its replacement), optimizing/prioritizing a program, and implementing predictive maintenance concepts. RWP instructions could be incorporated at various levels of initial and continuing education and training programs offered by the Air Force

Civil Engineer community. Additionally, on-line training courses could be developed to bridge the gap between formal instruction, and RWP could be discussed in articles in the organization's periodicals (e.g., The Civil Engineer Magazine). Official regulations and other guidance that reference RWP should be updated to reflect changes to the program and provide additional instruction on the program. Furthermore, leadership should take advantage of every opportunity to place future managers in positions where they can get practical experience with the RWP.

To serve as a starting point for the creation of a standard curriculum for RWP education, the 'RWP Education Curriculum Guide' was developed. Found in Appendix D, it consists of a list of suggested RWP-related topics that individuals who work with the program should understand in order to improve their effectiveness with the RWP. To align it with existing training venues, it is organized according to position/role within Operations Flight. The curriculum suggested in this guide was based on input from the interviews and information acquired through the literature review.

*Focus Area #4: Leadership Attention*

Leadership attention to the RWP is necessary to ensure the program receives the appropriate level of support and resources. Leadership at all levels of the organization must set clear priorities with respect to the program, provide manpower and resources accordingly, ensure proper education and training is provided, and hold personnel accountable for performing the work. Leadership can also help with de-conflicting/facilitating multi-craft RWP, annual program reviews, and engineer/craftsman interaction. Ideally, RWP should be the #2 priority after emergency and urgent work orders, which in Air Force terms is called Direct Scheduled Work (DSW). Furthermore, RWP should take precedence over the numerous additional duties that CE

performs; however, RWP is usually the first type of work that is deferred or skipped in light of other requirements. If the RWP is not a priority, leadership should state as such and expect to have more emergency DSWs and higher long-term costs; otherwise, leadership should provide the appropriate level of support and resources to the program.

This focus area was supported by several findings from the SWOT analysis: S1, W1, W3, W4, W5, W6, O6, O7, O8, T6, T7, and U3. Enhanced leadership attention to the program could draw attention to and fix the weaknesses and threats, and it is critical to ensuring the level of support necessary to exploit the strengths and opportunities. In order to improve leadership attention to the program, leaders should be educated on the potential benefits of the RWP and fully informed of the program requirements. By improving the accuracy of records and producing quality metrics, shops will have the justification to advocate for resources and gain support from their leadership for the program. If leaders at all levels of the chain of command understand the importance of RWP, they will be more likely to give it the priority and emphasis it needs.

When making decisions that affect the RWP, leaders should be aware of the level of risk associated with a given decision. To facilitate RWP risk assessments, the 'Risk Classification Guide' was developed; it can be found in Appendix E. This concept provides a framework for identifying the risk category for a given equipment item or system, and is an extension of the RWP Review Guide and Decision Tool. It was developed based on information gathered during the literature review and interviews, and it also includes some helpful examples of equipment that meet each classification.

*Focus Area #5: Common RWP Standards*

Common RWP standards across the Air Force are a great way to reduce the time, effort, and guess work involved in creating and updating an RWP. Common RWP standards should consist of craft-specific Maintenance Action Sheet (MAS) templates and guidance developed with coordination between craft-specific functional experts, engineers, and operations support staff at a centralized organization (i.e., the Air Force Civil Engineer Support Agency, AFCESA). RWP requirements for certain equipment will vary from base to base due to different mission requirements and environmental conditions; as such, the common standards should not serve as strict requirements, rather they should provide a starting point for developing a program and a common basis for program review/evaluation. These common standards would be very similar in concept to the contingency equipment kit guidance currently provided by AFCESA which provides parts/equipment lists, packing/building instructions, and other references.

Many findings from the SWOT analysis supported this focus area; they included W1, O1, O2, O3, O8, T1, and U1. If used as a baseline when creating or reviewing the RWP, these standards could help save a lot of time, effort, and guess work for the individual units. Craft-specific standards could be developed according to equipment type and ranges of equipment size; associated guidance could consist of recommendations for optimal equipment brands, percent of shop time to devote to RWP, annual review procedures, RWP MAS templates, RWP frequency recommendations, and work/equipment priorities for different types and sizes of equipment. These standards could be disseminated in a variety of ways, to include the Operations Support CoP that already exists on the Air Force Knowledge Now website. In addition to posting the standards, this mechanism would also allow members across the Air Force to contribute to developing the standards. Although units should be allowed to tailor the

program to best suit their needs, these standards could still be used as a common basis for comparison between different units' RWPs.

To provide an example of the types of common standards that could be developed, the 'Common RWP Standards Concept' was developed. The concept can be found in Appendix F, and it gives two types of examples. The first is a set of flight-level standards that apply to the entire maintenance operation (regardless of craft), while the second is a set of craft standards that apply to each craft or shop as a separate entity. These suggestions were developed based on information gathered during the literature review and input obtained during the interviews.

*Focus Area #6: IWIMS Replacement*

In its primary capacity, IWIMS serves as the CE community's current computer-based maintenance management system (CMMS), and it has been in use since it was first introduced in the early 1980s. Over the last ~25 years, CMMS technology has improved exponentially; therefore, IWIMS needs to be replaced to take advantage of these improvements. This effort could positively influence nearly all aspects of the RWP, but it would require a significant amount of resources and leadership support to accomplish.

This focus area was supported by seven findings from the SWOT analysis: W1, O1, O2, O3, O8, T1, and U1. When developing this system, it should be designed to be more user-friendly and easier to update/review. Additionally, it should have built-in mechanisms for evaluating the cost effectiveness and risk associated with the RWP for a given equipment item or system. The next IWIMS should also have built-in guidance for developing RWP actions, tracking equipment history, monitoring equipment warranties, and supporting new metrics for gauging the success of the program. Another potential technology to consider integrating into

the new CMMS is bar-code/scanner technology, which could drastically improve equipment inventory updates and the tracking of actual labor hours spent maintaining equipment items and systems.  To facilitate annual program reviews, the new program should incorporate optimization features that balance the size of the overall RWP based on available resources and inputs from management; the ‘RWP Review Guide and Decision Tool Concept’ discussed in Focus Area 2 and shown in Appendix C provides a framework for these optimization features.

*Focus Area #7:  Predictive Maintenance*

Predictive maintenance, also known as conditions-based maintenance, consists of performing actions only when needed (i.e., prior to failure) rather than according to a set schedule.  These maintenance needs can be identified by either routine equipment inspections or remote sensing equipment.  Inspections require less manpower than full maintenance actions, while remote-sensing equipment requires even less.  Additionally, predictive maintenance methods can help conserve resources since resources are only consumed when absolutely necessary.  While preventive methods should still be used for some mission or life-critical equipment and systems, predictive methods can and should be utilized whenever applicable.  A combination of preventive and predictive methods can also be utilized to optimize individual RWP actions; for example, within a single maintenance action, predictive methods could be used to determine when to replace complex parts while preventive methods could be used for simple tasks like cleaning and lubricating.

Three findings from the SWOT analysis supported this focus area:  O2, O3, and U2. To increase the use of predictive maintenance methods, personnel should be educated about the benefits and trained on implementation.  Leadership must provide the encouragement to

transition to predictive methods and be willing to accept any changes to the status quo. Air Force-wide common guidance could be developed to identify candidate equipment or best practices for making the transition to predictive maintenance. As funds and technology allow, consider installing and increasing the use of remote sensors for conditions-based maintenance, thereby reducing the manpower requirements of the program. As always, accurate recordkeeping must be enforced and quality metrics must be developed in order to demonstrate program performance; similarly, annual reviews must be accomplished in order to tweak inspection frequency and optimize the program.

An example of remote sensing conditions-based maintenance that is currently utilized within the Air Force is the Energy Management Control System (EMCS) used by the Heating, Ventilation, and Air Conditioning (HVAC) shops at many installations. With EMCS, there are remote sensors and controls in nearly every facility on base that are linked to a central control station. When the system identifies discrepancies between pre-set temperatures and actual temperatures, schedulers are notified and a craftsman can be dispatched to correct any system discrepancies. This concept could be used in many other capacities and for many different types of equipment – various sensors could be used to gauge equipment condition and identify when maintenance is required. This technology has the potential to drastically change how the RWP is performed.

*Focus Area #8: Redesigned Metrics*

The final Focus Area deals with the metrics that are used to gauge the effectiveness of the program. The current metrics for RWP focus solely on a shop's ability to charge labor to the program by comparing the number of RWP hours scheduled to the number of RWP hours

completed for a given reporting period. By changing the metrics to provide information that accurately portrays program performance, the metrics could be used to drive improvements to the program. Furthermore, improved metrics could be used to identify specific aspects of the program that need to be modified.

There were four findings from the SWOT analysis that supported this focus area: W4, O2, O4, and T1. An example of a new metric that could be developed using the current IWIMS is tracking the number of skipped or deferred RWP actions for a given period to gauge the effectiveness of a shop's scheduling procedures. Additionally, a metric to track when program reviews are completed would help determine when future reviews are needed and performed. Further details for these two new metrics are provided in Appendix G, the 'New RWP Metrics Concept.' This concept provides instructions for calculating the metrics, identifies all required data fields and necessary calculations, and explains the potential value of such metrics. Furthermore, it serves as a useful reference that could be used to build these metrics into the next generation of IWIMS.

Based on the information and capabilities currently available through IWIMS, the possibilities for new metrics are somewhat limited; however, capabilities could be designed into the next generation of IWIMS that would allow new and more powerful metrics. An example of a metric that could be developed if new capabilities were available is a metric to gauge the standard deviation between estimated and actual labor for individual maintenance actions; this type of metric could identify the accuracy of the MAS and where program updates are needed. Another possible metric could compare the costs of RWP to a system's life cycle costs or the costs of unscheduled maintenance in order to gauge the effectiveness of the program.

## Summary

This chapter provided an explanation of the analysis and model development results from this thesis. In the first portion of the chapter, the results of the SWOT analysis results were explained, while the second portion of the chapter discussed the model and recommendations for modernizing the RWP. Additionally, five implementation concepts were introduced – each of these concepts provides practical suggestions for implementing various aspects of the Focus Areas, and they can be found in Appendices C through G. For additional reference, summary charts for the SWOT findings and Focus Areas are located in Appendices H and I, respectively.

# 5. Conclusion

## Thesis Purpose

The original intent of this thesis was to develop a decision model for preventive maintenance that considered risk, cost optimization, standardization, and practicality. Over the course of the thesis effort, the purpose evolved into developing a framework for evaluating and modernizing a preventive maintenance strategy. This expanded purpose not only addressed the original intent of the thesis, but allowed the research to delve further into the subject area. As a result, the thesis was able to provide a more complete basis for evaluating and improving an entire preventive maintenance strategy rather than just a small portion or single aspect.

## Thesis Overview

The thesis objective was accomplished through the performance of a case study of the Air Force's preventive maintenance program known as the Recurring Work Program (RWP). This program plays a significant role in the Air Force's facilities and infrastructure maintenance operations (a brief history of the program is provided in Appendix A). The challenges facing the Air Force and its RWP are not unlike the challenges facing many other organizations and their respective preventive maintenance programs. Even though the Air Force is an extremely large public sector organization, lessons learned from this thesis can be applied by nearly any organization interested in evaluating and modernizing their preventive maintenance strategy.

The case study consisted of four primary activities: literature review, data collection, data analysis, and model development. These activities were mostly sequential, although there were overlaps of multiple activities at any given time throughout the course of the thesis effort.

The next section of this chapter reviews the methodology, which explains how the separate activities fit together.  It is followed by a brief review of each of the four primary activities.

*Methodology*

In order to accomplish the intended purpose of this thesis, a two-part methodology was developed.  The first part consisted of a needs analysis that focused on understanding the condition of the current program and what it needs to become in order to provide the most benefit to the organization (in this case, the Air Force).  The needs analysis began with a comprehensive literature review to develop an understanding of the relevant theory, and it continued with a thorough data collection which consisted of interviews to obtain expert insight into the current program.  Using the literature review and interviews as a foundation, a Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis was performed; this analysis provided a comprehensive depiction of the current RWP and what it needs to become.

The second part of the methodology consisted of developing a practical model to bridge the gap identified in the first part of the methodology.  This effort began with further developing the findings from the SWOT analysis by providing a recommendation for further action for each finding.  Once these recommendations were complete, they were compiled, de-conflicted, and strengthened to produce a practical list of ’Focus Areas’ which effectively comprise the model for improving the RWP.  The last effort in developing this model consisted of creating concepts and suggestions for the practical implementation of each focus area.

*Literature Review*

The purpose of the literature review was to capture all relevant information, theories, and concepts that apply to this analysis of preventive maintenance strategies. It covered six primary topics: maintenance management, common maintenance strategies, maintenance optimization, decision analysis, asset management, and applied maintenance practices. Each topic contributed to developing an extensive foundation from which to fully examine and evaluate the RWP.

*Data Collection*

The data collection was intended to provide the necessary information to develop a comprehensive understanding of the current RWP, to include problems, benefits, and desired changes. It consisted of interviews with knowledgeable members of the career field who had a variety of backgrounds and experiences with the RWP. In total, 25 interviews were held; this quantity proved to be sufficient in the fact that common themes and gaps were clearly evident across the responses. Additionally, there was sufficient evidence to support each of the findings in the data analysis portion of the thesis. In terms of experience, the subject pool met all expectations with an average of approximately 22 years in the CE career field, a wide variety of past and present roles with respect to the RWP, and a wide variety of past assignments. The interviews were conducted in one of two formats at the discretion of the interview subject; the first was a personal interview conducted either by phone or in person, the second was a self-paced electronic interview conducted via e-mail. All interview responses, sanitized to remove any references to subject identity, can be found in Appendix B.

*Data Analysis*

Data analysis was accomplished using a method known as a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. The SWOT analysis was utilized to develop an understanding of the current program and how it needs to change. It consisted of identifying common themes in the interview data and best practices in maintenance management industry as identified during the literature review. In total, this SWOT analysis identified one strength, six weaknesses, eight opportunities, and seven threats to the current RWP. Additionally, there were three findings that could meet multiple classifications depending on conditions; these were labeled 'unclassified'. A summary chart of the SWOT analysis results is located in Appendix H.

*Model Development*

As stated in the methodology, the model for the foundation to transform the RWP consisted of a series of 'Focus Areas' – each focus area is unique theme of practical recommendations for improving the program. There were 8 focus areas that comprised the final model, and they were developed by compiling, de-conflicting, and strengthening the recommendations from the SWOT analysis. These focus areas fell into three categories – the first category consisted of two concepts that are part of the current RWP, but which have been severely neglected. In the second category there were two aspects that are not necessarily part of the current RWP, but are basic concepts stressed throughout maintenance management literature. The final category included four concepts/ideas that take advantage of new technology and best practices in industry that have the potential to take the program to the next level of performance. For a summary chart of the focus areas, refer to Appendix I.

As part of the model building process, a series of implementation concepts were developed. These concepts provide practical suggestions for implementing the focus areas, and consist of the following:

- The 'RWP Review Guide and Decision Tool' (Appendix C) provides a step-by-step framework for reviewing a RWP which incorporates both cost and risk considerations.
- The *RWP Education Curriculum Guide* (Appendix D) is a list of RWP-related topics that individuals who work with the program should understand in order to run an effective RWP.
- The *Risk Classification Guide* (Appendix E) provides a framework for identifying the risk category for a given equipment item or system.
- The *Common RWP Standards Concept* (Appendix F) explains the idea of organizational standards could work and provides suggestions for types of information to include.
- The *New RWP Metrics Concept* (Appendix G) provides instructions for creating two new metrics, and identifies all required data fields, calculations, and supporting information.

**Further Research**

There are numerous potential areas for further research that could follow this thesis effort, but there are four areas that seem particularly promising. The first area consists of research into computerized maintenance management systems, and it could be based on a case study for the development of the next generation of IWIMS (as suggested in FA#6). Research would entail investigating the latest maintenance management technology/programs and exploring their potential role within and impacts upon a maintenance operation. The next consists of research into enterprise maintenance standardization for large scale maintenance operations. This concept is gaining popular within industry as part of the Asset Management

field of study, and it could be based on a case study for development of common standards for CE (as suggested in FA#5). Research could include investigating standardized approaches to maintenance and exploring the advantages/disadvantages, best approaches, and optimal levels of standardization for a large scale maintenance operation. A third potential research area lies in evaluating the effectiveness of implementing the recommendations from this thesis – as depicted in the history of RWP (Appendix A), numerous efforts have been made to improve the RWP over the years – yet the same problems perpetually exist within the program. It could be interesting to see if this thesis can make an impact and to explore the factors that contribute to its success or failure. A fourth topic for further research is evaluating implementation and utilization of the RWP in a contingency environment. The results of such a study could be valuable to the Air Force for understanding different approaches for applying RWP at home station and deployed locations.

**Conclusion**

The primary purpose of this thesis was to develop a framework for evaluating and modernizing a preventive maintenance strategy; it was performed through a case study analysis of the Air Force RWP. Information gathered during a thorough literature review and a series of interviews formed the basis for a SWOT analysis which identified problems and gaps within the existing program. The results of the SWOT analysis contributed to the development of a model consisting of eight focus areas for modernizing the program. This model and the process used to create it provide the foundation for improving the Air Force RWP and a framework for evaluating and modernizing any preventive maintenance strategy for facilities and infrastructure.

## APPENDIX A. History of the Air Force Recurring Work Program

This appendix captures a brief history of the Air Force Recurring Work Program (RWP) in order to provide a glimpse into how the program came into existence and explains how it developed into what it is today. Historical references about the RWP are rare, but the following account is based on historical references captured from two sources. The first source consists of an interview held with Col Thomas L Glardon (USAF, ret), formally the Director of the Department of Engineering Management at the Air Force Civil Engineer and Services School. Having spent 22 years in the career field, Col Glardon has a wealth of experience in the Air Force Civil Engineer Community; of particular interest for this research effort, Col Glardon co-authored the first Maintenance Engineer Handbook (AFPAM 32-1004, Version 2) in 1994. Aside from minor revisions, this handbook still serves as the current primary reference for the RWP. The second source consists of an Air Force Institute of Technology thesis by then Captain James A. Jackson. His thesis, titled “Facility Reliability and Maintainability: An investigation of the Air Force Civil Engineer Recurring Work Program” was completed in 1989, and it provides a thorough historical perspective of the RWP between the years 1978 and 1989. Captain Jackson cited 6 sources in the material used in this history; however, perhaps due to the time since his thesis, only one of these sources could be located for direct reference in this paper.

Preventive maintenance serves as the basic concept behind RWP – extending the life of equipment and reducing the likelihood of emergency failures through performance of routine maintenance actions. The concept of preventive maintenance has likely been around since man developed the world’s first machines; likewise, the basic concepts of RWP have been in practice since the first Air Force Civil Engineers began maintaining facilities and infrastructure on Air Force installations (Glardon, 2008). Although the program name and particulars varied during

the earlier years of CE, the RWP as it is known today developed around the late 1970's/early 1980's with the advent of the Air Force CE Community's first computer-based maintenance management system called the Integrated Work Information Management System (IWIMS). This transition basically took existing scheduling procedures that were being performed on paper and converted them to electronic format (Glardon, 2008). This effort established the basic work order and RWP systems that are in use within the CE community today.

Broken down to its simplest form, the RWP process consists of 5 steps (Glardon, 2008). The first step consists of the actual the installation of a system or piece of equipment. One installed, the second step of the RWP process is creation of the preventive maintenance action. Creating a preventive maintenance action includes developing a set of tasks, estimating the amount of time to complete the tasks, and establishing the appropriate recurring frequency for conducting the tasks. As discussed in the literature review, there are many sources of information to assist with determining the maintenance action for a given system or piece of equipment. Once developed, this information is captured on an Air Force Form 1841, also known as a Maintenance Action Sheet (MAS), which serves as an instruction sheet for the craftsman to perform the RWP. Inputting the MAS into IWIMS is the final task of the second step. The third step of the RWP process simply consists of IWIMS notifying management that an RWP action is due. This step is automatically accomplished by IWIMS; however, the system's ability to accomplish this task relies solely on management's ability to input the appropriate information into the system. If IWIMS is unavailable or inoperable, this step can also be accomplished manually or with any other capable computerized maintenance management system.

When IWIMS notifies management of an impending RWP action, the fourth step of the process consists of the action taken by management in response to the notification. There are three possible responses to each notification: perform the action, defer (delay) the action, or cancel the action. The fifth step of the process consists of entering relevant information and updating IWIMS based on actions performed. At this point in the process, it is management's responsibility to identify trends in the actual performance of the RWP maintenance actions and update IWIMS to ensure it operates as efficiently as possible. For example, if the actual amount of time required to perform an action is repeatedly more or less than the estimated time, the time estimate should be updated accordingly in IWIMS. Similarly, if an action is repeatedly delayed or canceled with no noticeable effect on the equipment or system, the frequency should be altered or the action should be cancelled. However, if the RWP actions are performed as scheduled and if there is no substantial difference between actual and estimated performance, no actions are required beyond logging relevant information about the completed work. Proper performance of this step of the RWP process is critical to ensuring IWIMS develops the most efficient work schedule.

In the 1970's and 1980's, Air Force unit manpower was determined according to justified workload, rather than mission requirements which serve as the current manpower basis (Glardon, 2008). Manpower teams would visit an installation every 1-2 years to meet with various leadership personnel and review unit performance reports. These visits were similar to a modern-day IG inspection, but the end result was a manpower figure for each unit which determined how many personnel the unit was authorized. Under this system, units were indirectly encouraged to show large amounts of unfinished work in order to justify increased personnel authorizations. RWP became a popular mechanism for creating additional work

requirements, and was often abused – in some cases, frivolous or excessive RWP actions were created to increase the amount of incomplete work and justify additional manpower (Glardon, 2008).

Numerous problems with implementation of the RWP were identified as early as the mid 1970's when the Operations and Maintenance Directorate, Headquarters Air Force Systems Command commissioned a two year study to analyze the program (Jackson, 1989). Captain P. J. Toussaint and MSgt Louis Collachi published the results of this study in the May 1978 issue of Engineering and Services Quarterly in an article titled, "The RMP […] a system to insure control over decreasing resources." (Although the title of the article cites the Recurring Maintenance Program (RMP) rather than RWP, recall that the program had various names in its earlier years but consisted of the same basic concepts and processes.) Toussaint and Collachi emphasized the need to improve two specific aspects of the program: management's role and craftsman education. Additionally, they compiled a checklist of RWP indicators, as shown in Table 1.

| |
|---|
| MAS descriptions too broad and general |
| MAS reflects tasks not accomplished on every visit |
| Excessive frequencies |
| All similar equipment/systems not covered by one MAS |
| Dissimilar equipment covered by one MAS |
| MAS not reflecting building number's where visits are to be made |
| Equipment listed in the file is not operational/installed |
| RWP requirements not included in Ops work list |
| RWP file not purged of non-critical items under $250 |
| Start/stop months not included |
| RWP file not purged of seasonal overhaul requirements |
| Requirements from outdated manuals not deleted |
| Duplicate visits no deleted |
| Expiration of warranty pick-up procedures |
| Annotation of standard hours on completion cards |
| Duplicate inspections performed by craftsmen and planners |
| No review and validation of MAS by foreman, superintendent, and operations chief |

Table 1. Indicators of Poor RWP Performance, May 1978

In 1981, Military Airlift Command (MAC) initiated an intensive study of RWP across its bases due to the fact that poor RWP performance had been mentioned in nearly every Inspector General (IG) inspection the previous year (Jackson, 1989). Write-ups cited a lack of aggressive management attention as the source of the problem, and repeat offenses were gaining the attention of commanders at all levels. The product of this study was a list of nine recommendations to improve RWP, which are shown in Table 2.

| | |
|---|---|
| 1 | Each base should review their RWP and remove or extend the maintenance interval of any item that cannot be economically or mission justified. |
| 2 | Screen the recurring maintenance file list and the operation and service maintenance action sheets for duplications. |
| 3 | Discontinue maintenance of low cost items unless such maintenance is clearly recommended by the manufacturer or economically justified. |
| 4 | Use engineering performance standards to estimate man-hours for RWP and operation and services. |
| 5 | Use EMCS more extensively to monitor equipment system status. Rely less on operator checks and move toward a response to abnormal conditions methodology. |
| 6 | Consider involving facility users in inspection and minor maintenance actions. |
| 7 | Ensure life expectancies are realistic. |
| 8 | Review collection work orders in the RWP annually in conjunction with the fiscal year review of collection work orders and the work authorization list. |
| 9 | Ensure that maintenance actions are assigned and performed by the cost center with the capability to accomplish it most efficiently. |

Table 2. 9 Recommendations to Improve RWP, MAC, 1981

These nine recommendations are not entirely different from the list of 17 indicators of poor performance, but they served to re-emphasize the importance of a few key factors for a successful RWP. In 1983, MAC issued an official maintenance management philosophy statement, which encouraged further management attention on the RWP (Jackson, 1989).

In 1985, Strategic Air Command (SAC) issue a list of the eight elements of a good RWP. SAC emphasized the importance of management attention to these eight elements in order to lead to a lower emergency/urgent job order rate, lower operations and maintenance costs, lower energy costs, and more available shop time (Jackson, 1989). The list of the eight elements is shown below in Table 3.

| | |
|---|---|
| 1 | Preventive versus breakdown maintenance |
| 2 | Equipment history |
| 3 | Prioritize needs/frequencies |
| 4 | Tools for successful RWP |
| 5 | Detailed information of each item |
| 6 | Management Review |
| 7 | Record keeping |
| 8 | Design |

Table 3. 8 Elements of a Good RWP, SAC, 1985

In 1988, Headquarters Air Force released Air Force Regulation (AFR) 85-2, Civil Engineering General, Operations Management (Jackson, 1989). This was one of the first official regulations to govern the RWP. This regulation touted the benefits of an effective RWP, delegated responsibility for the program, and outlined recommended procedures. The 8 benefits of the program, as stated in AFR 85-2, are shown in Table 4.

| | |
|---|---|
| 1 | Cost effective real property maintenance |
| 2 | Proper maintenance of active real property |
| 3 | Reliable utilities and efficient energy use |
| 4 | Preventive maintenance accomplishment |
| 5 | Maximum customer service |
| 6 | Maximum production |
| 7 | Effective resource allocation |
| 8 | Positive work force control |

Table 4. 8 Benefits of an Effective RWP, AFR 85-2, 1988

Full responsibility for the program was delegated to the shop supervisors and superintendents, and they were directed to give recurring work the third highest priority after emergency and

urgent work orders (Jackson, 1989). Procedures for implementing RWP, as outlined in AFR 85-2, included establishing an equipment inventory, identifying maintenance requirements, preparing MAS, scheduling maintenance activities, and reporting status (Jackson, 1989).

In 1992, the Air Force introduced various operational and procedural changes under a program known as Quality Air Force (QAF). The intent of QAF was to improve the efficiency of Air Force operations by mirroring practices of successful private sector organizations. In response, the CE community developed its own series of improvement initiatives through an effort known as the Objective Squadron. There were two primary changes that resulted from these initiatives which had profound effects on the RWP (Glardon, 2008). The first change was the establishment of the Maintenance Engineering element within the Operations Flight; it was composed of degreed engineers who could apply their technical expertise to Operations Flight programs. While the shops were still responsible for establishing and executing RWP maintenance actions, the newly formed Maintenance Engineering element was given the task of oversight and evaluation of the RWP. The second change altered the Air Force manpower basis from workload to mission requirements. As a result of this change, the indirect encouragement to show large amounts of uncompleted work in order to justify additional manning was no longer a factor for developing RWP actions. By introducing technical experts to the program, establishing clear lines of responsibility, creating an evaluation/review framework, and changing the incentive for the success of the program, these two changes created an opportunity to streamline the RWP and improve the effectiveness of the program (Glardon, 2008).

AFR 85-2 was replaced by Air Force Instruction (AFI) 32-1031 in 1994, the same year that the “Working in the Operations Flight” Air Force Pamphlet Series (AFPAM 32-1004, Volumes 1-6) were developed. Volume 2, which has become known as the Maintenance

Engineering Handbook, became the primary reference for the RWP. Chapter 8 of the Maintenance Engineering Handbook covers the RWP. It discusses the benefits of a properly implemented program, basic definitions, recommendations for implementing and developing a program, a detailed example of the life-cycle cost analysis method, alternative analysis methods, and organizational roles and responsibilities for the program. In 1999, AFI 32-1031 was replaced with AFI 32-1001, "Operations Management," and the AFPAM 32-1004 series became the official supporting reference for AFI 32-1001.

Since the first Maintenance Engineering Handbook was developed in the mid 1990's, it has remained the official reference for the RWP. Aside from a few minor updates to the pamphlet and a handful of local changes at individual units, the RWP has remained the same basic program over the last 10-15 years. During the same time period, however, the Air Force and the CE community have experienced numerous changes in areas such as culture, technology, budget, threats, manpower, and more. Throughout the nearly 7 years of the Global War on Terrorism, weapon systems have aged and the size of the force has been reduced; resources are shrinking and operating costs are increasing. In response, the Air Force has once again identified the need to examine operational and procedural changes aimed at further improving the efficiency and effectiveness of how it operates. This effort, known as Air Force Smart Operations for the 21st Century (AFSO 21), is focused on examining every basic process to identify ways to eliminate waste, generate efficiencies, and improve combat capabilities (AFSO21 Office, 2007). The Civil Engineer community has followed suit with its own initiative known as CE Transformation. As with the QAF movement in the early 1990's, CE Transformation is encouraging the CE community to investigate ways to reduce costs and improve efficiency in its core business processes and mission support capabilities (Gaub, 2007;

Eulberg, 2007). This effort involves exploring every aspect of how the CE community operates, to include approaches, methods, and tools, and incorporating changes where needed (Culver, 2007). One of the main initiatives within CE Transformation is a shift to an asset management culture. Some of the concepts addressed by asset management are: common levels of service and standardized CE processes across the AF; a capability to analyze and communicate best business cases based on risk, cost, and benefits; a predictive capability across infrastructure lifecycles; and a way to credibly advocate for and allocate resources (Lawrence, 2007). Leaders within the CE community are encouraging members to think outside the box, and they emphasize that new ideas and initiatives should not be tied to predetermined expectations (Gaub, 2007). "Transforming AF CE is not only a necessity, but also an opportunity. It's an opportunity to shape the future by changing how CEs do their jobs today" (Culver, 2007).

This brief history of RWP has provided insight into the beginnings of the program, its development, its hurdles and milestones, and a broad understanding of the challenges it currently faces. RWP is just one of many programs used by the CE community, but it plays an important role in their ability to provide expert installation support for the Air Force. Efforts to improve this program could shape the future capabilities of Air Force CE.

## APPENDIX B. Interview Response Database

This collection of interview responses is organized into two sections. The first section consists of 5 questions that were addressed to all interview subjects; the second section consists of various follow-up questions that were addressed to individual interview subjects based on their responses to one of the first 5 questions. Original responses from the interviews have been edited to 1) convert conversational format to written format, 2) remove all references to personal identity, and 3) improve reading flow. Each question is posted in bold-face italics, and all responses are listed in bullet format below the corresponding question.

### Section 1: Common Questions (addressed to all interview subjects)

***Question 1: In your opinion, is/was RWP worthwhile? Why? Explain any particular strengths or weaknesses.***

- RWP is worthwhile because it defers capital investment through a long term preventative maintenance program. Strength is being able to schedule a multiple number of assets for routine maintenance. The weakness is the evaluation the life cycle cost to determine if RWP is worth the effort for a particular asset.
- From a utilities perspective I felt it was worthwhile based off the amount of maintenance required...mainly for fire suppression systems and backflow preventers. Strengths; provides historical maintenance data, validates man-hours utilized/needed, provides as an accurate reminder to accomplish required maintenance. Weaknesses; virtually the same program has been in effect for 20+ years. Certainly technology has changed dramatically over the years...is there a better program out there that would meet AF needs?
- A measured, deliberate approach to RWP can be worthwhile if the service life of an item is extended. Making a conscientious decision to exclude some low-value items from RWP can free man-hours to perform better maintenance on other items. Blindly following manufacturer's recommendation can be costly and not reap the benefits expected. Will a car engine that has its oil changed every 3,000 miles last that much

longer than an engine serviced every 6,000 miles…or will the vehicle be replaced before the engine fails from poor oil, which makes the 3,000 mile oil changes a wasted expense.

- RWP is worthwhile because it's about taking care of government assets. If you just let a system break down, you may not be able to get parts or it can affect your schedule, so RWP can help stretch your dollar and save you time. Back in the early 90's we got rid of a lot of people, but we were still required to do the same amount of RWP. The records weren't updated to reflect the manning that we have now, so you got a lot of shops that would pencil whip it; that's where you run into problems with the system breaking down because systems weren't maintained as they were scheduled. I've been at other bases where they've done it well - they develop schedules based on manufacturer's recommendations, maintain the equipment according to what they see, and adjust their records.
- RWP is worthwhile; it extends the life of equipment and systems and saves the Air Force dollars in preventable failures. It also adds a great deal of safety for individuals who are required to turn equipment/systems on and off. A case in point: turning electrical switch gear on – not having performed RWP could cause lose connections and cause an explosion or fire and long term power outage to base populace and possible bodily harm.
- Yes, I definitely think it is a worthwhile program. There does have to be some common sense applied to the program though. For example, conducting RWP on a small inexpensive item such as a ceiling fan might not be worth the time/effort; in such cases it is probably better to just let that small inexpensive item fail and then replace it. But for large items RWP is extremely important and saves the AF a ton of money in the long term. One of the main strengths of RWP that I see is that if used properly and if the data is collected/analyzed properly it can pay huge long term dividends for the base. A good analogy is having your car serviced every 3,000 miles. While your car is being serviced the technicians may find something wrong that could lead to a catastrophic failure of your engine which would cost thousands of dollars to fix (or replace). By finding the problem early they may be able to fix it inexpensively and prevent that catastrophic failure.
- An advantage of the RWP program is it can provide indications of design flaws, units being improperly sized/installed/positioned, etc. For example, if you have to change filters and belts on an A/C unit way too often the unit may be undersized and working too

hard and need to be "reengineered" and replaced with a larger unit. Or if excessive RWP is being done maybe the unit was installed improperly and needs to be reinstalled. Using the RWP data to diagnose problems can lead to huge dividends. Using RWP data can also help track down "energy hogs" and find areas to save money and find new/better/more efficient solutions to problems.

- RWP definitely has its advantages. There are no disadvantages to RWP; however the cost effectiveness of some systems may not prove worthwhile. RWP is a very expensive part of any maintenance program. A cost analysis may prove that up to 50% of actions completed today could possibly be abolished and repaired when they break.
- RWP is a worthwhile program--we are not getting the MILCON and/or SRM dollars needed to replace and repair our infrastructure. RWP is one method of ensuring that our infrastructure can continue to meet mission requirements. I think the strengths of the RWP continue to be the program itself. It is a good program but if the program is not executed we will not see the results we would like. A weakness is the lack of manpower we continue to experience.
- I think RWP is definitely a worthwhile program. I don't believe RWP in its current state is a productive and efficient program, but worthwhile. I think major renovations and major cultural changes in how we approach, attack, perform, and fund RWP are needed, and when I say culturally, I mean from the leadership down. Preventive maintenance is preventive maintenance; we all know it's important. But the sky is not the limit. Especially in the constrained environment we are in with competing resources (time and money). When is RWP constructive vs destructive? How much manpower do you put on a $1000 pump? Or do we just let it blow up, and we'll replace it when it fries? Why put a million man-hours and dollars in it inspecting it every week just in case? It never blows up when you're watching it; at least not while I've been watching. RWP is supposed to be our number one priority; but it's the first thing we all cut hours (and $$$) from and the last bit of attention we get to – you have to ask, "why are we doing it?" For some of our shops, RWP is their life: virtually every shop but more prominent in power pro, HVAC, LFM, and even electrical shops. In my opinion, we have reverse engineered RWP. We pad RWP hours to justify manpower instead of determining the craft hours we need and developing RWP around that. What's the minimum we need to go by – I think

we’ve gone overboard in how we approach that. Supervisors are not scheduling RWP properly in their weekly schedules because they’re using it to zero out the available hours; we have some inherent inefficiencies in the military (i.e. training) but this does not excuse the way RWP is being used. When I look at weekly work schedules during inspections and shop visits, I can tell within minutes if they’re pencil whipping RWP as the actual hours match the scheduled hours. When you deploy, the AFI says you can cut the RWP but numbers aren’t showing this – units are saying they’ve completed all RWP, but yet they have 40% of manpower gone? How? Pencil-whipping; we use RWP as a paperwork drill. We’ve allowed the program to erode because we don’t have the time. If you’re saying you’re doing the work and you’re not really doing it, 1) you’re falsifying an official statement and you’re lying, 2) you’re not advocating to anybody that you’re short on manpower. It’s not possible to do the same amount of work with 40% of your manpower gone, so what you’re telling me is that you don’t need that 40%. RWP needs to be proactive. First thing I do when I get a new piece of equipment is build an RWP, then I need to reevaluate every year to make sure what I’m doing is still working. If I’m doing a certain frequency and having no problems, maybe I need to scale back. We own the play book on RWP. We decide what we’re going to do, how we’re going to do it, when we’re going to do it, yet still we can’t seem to pass the test. Too many units are pencil whipping to look good; that is a big mistake because they aren’t showing an accurate representation of the state of the equipment or the work that is being performed (or not getting done). CE is sometimes its own worst enemy at this. We say we can’t do it then we turn right around and do it anyway. CE can do anything, we just can’t do everything. This is where we fail as we do not communicate that well enough to leadership and makes the point we have the manpower and money to complete all our work. Not true.

- Could it be? Yes. Is it? No, because it is not managed in such a fashion that we apply our lessons learned to our equipment. We don’t make good decision on what things to run to failure; we don’t apply industry standards when we write our MAS sheets. The structure isn’t right for getting a good result. When we made decisions about cutting things from the program, we don’t make educated decisions.

- Yes, I believe RWP is worthwhile, but it needs to be updated and hopefully standardized AF-wide. First, we probably need to perform RWP per manufacturer's instruction in order to keep the warranty in effect. Once the warranty period is over, then the RWP program for that equipment needs to be reviewed and adjusted based on shop availability, life-cycle cost, and other parameters. Currently, more often than not, once a RWP record is created, it is rarely reviewed or adjusted based on real-world situations. The shop foremen and legacy maintenance engineers never had the training, time, or motivation to spend much time on making RWP efficient or effective.
- RWP is a worthwhile program for the simple fact that the automated system gives you reminders to guides you on the required maintenance that needs to be accomplished to extend the life of equipment. A strength of the program is that it is very thorough. A weakness is that there is no oversight on system reviews and updates. When the tasks are restructured, the shops go in and try to revamp the system without having a very good understanding of what needs to stay and what needs to go. They look at the overall process, maybe overlook some things, and decide for themselves what is needed and what is not needed. The effectiveness of the changes depends on the experience level of the person doing the review, but most Ops Chiefs just take the craftsman's word anyway.
- Yes, RWP is worthwhile in terms of putting eyes on systems in a proactive fashion and to proactively feed project programs. Weaknesses include too much complexity and too little effort to perform annual updates to retain the most valuable portions. Weakness also is in lack of visibility put on the program by Ops Chiefs and superintendents....leading to schedule slips or lapses. Need to beef up command emphasis on schedule compliance, with RWP being first priority after emergency/urgent work.
- Yes, it's always been a worthwhile program, but it depends on the integrity and mindset. When it's done right, it can save tons of job orders; I've seen strong programs that have cut emergency DSWs almost in half. I've seen it work perfectly – an example is Power pro – all they do is RWP; they take their job serious, they run their generators, they do the oil changes, etc. You have to have RWP for generators, but I've seen both spectrums good and bad. Too many times I've seen RWP fail for several reasons. For example, folks will go to do maintenance on a building, but the building is running ok, so they pencil-whip the RWP. As another example, a few years back they came out and said

we’re not going to do RWP on anything less than $500, because it’s not cost effective to do the maintenance. Even though that motor may have been less than $500, it may have been a very important component of a big system. So that motor would fail for some simple problem, and then the whole system would fail. It just never made sense to me, but we’re kind of getting away from that; we’re getting back to doing the RWP that’s important for the entire system instead of looking at individual components in the system. Another example that makes no sense is doing snow removal as RWP. RWP to me is a routine maintenance item that you do every single month or whenever, and I cannot predict or schedule RWP for snow removal.

- Yes, RWP is a worthwhile program if set up and maintained properly. A good program has been reviewed and small items have been removed and time allotted to concentrate on higher dollar items. For example, I think RWP is worthwhile on large HVAC equipment, and fire alarm systems as well as fire suppression systems. Some equipment is cheaper to replace rather than to maintain.
- Yes it is a worthwhile program especially when it comes to Mission Critical Facilities and equipment. It is necessary to have these items checked regularly so that operations are not interrupted.
- Yes! I've seen first-hand that a strong RWP significantly reduces equipment failures and associated emergency service calls. I started an Electronic/Control Shop from scratch in 1983 and inherited the base's Heating and Air Conditioning control system workloads with an average of five (5) emergency service calls daily. My personnel and I developed a comprehensive RWP and over the course of approximately 4 years, we drove emergency service calls down to approximately three (3) a month. Strengths of RWP is it maximizes the service life of systems (reduces plant replacement costs over the long run), and minimizes system downtimes for customers (improves customer satisfaction). The weakness of AF RWP is the Task Time Standards (TTS) used in developing maintenance action sheets. They are not really very accurate. For example, TTS reference Number GT 158 for removing a duplex receptacle (removal of cover plate, disconnect 4 wires and tape ends) is .1 (or 6 minutes). In my experience as an electrician, removing a duplex receptacle should only take one to two minutes at most. The error in time is exacerbated when there is multiple sequences on a task (i.e. - scheduling the removal of 10

receptacles equates to 1 hour using TTS standards, when in reality it should only take approximately 10 to 20 minutes.)

- I believe RWP can be worthwhile if properly managed. It was very difficult to change the frequency and Maintenance Actions Sheets. Where I have been it was difficult to get assistance from Maintenance Engineering. It was not that they did not want to help they had other priorities. To be successful it takes engineering and operations working together and the squadron placing a priority on its completion.
- Worthwhile? Yes. Strengths? Good RWP focuses shops on pro-active maintenance rather than reactive breakdown repairs, and it extends life of facility components. Weaknesses? Competes with special projects, major in-house repairs and work orders; to a degree, RWP limits wartime skill development for military.
- RWP is worthwhile. The strengths of preventive maintenance extends the life and increases the efficiency of high value assets; either as it relates to mission or cost. It is also an essential part of preserving repair/replacement warranty guarantees. Performing RWP also familiarizes craftsmen with the highly diverse set of complex systems so that in the event of failure, repair or replacement will be executed more efficiently. The weaknesses of RWP are primarily due to the current inflexibility of the antiquated software being used to manage the program. IWIMS RWP is not easily learned, used, or flexible enough to cope with the current ops tempo which requires close attention to available manpower and scheduled PMI requirements. There is also a lack of training provided to CE Craftsmen at all levels of their professional development on IWIMS RWP and the principles of RWP or establishment of a cost effective RWP program.
- I do believe RWP is worthwhile in some form. I wouldn't let my car go without the required periodic maintenance so there is without doubt equipment and systems out there on our bases needing the same sort of attention to prevent premature or catastrophic failure.

***Question 2: In your opinion, should the current RWP be changed? What can or should be done to improve RWP?***

- A big improvement would be a more current computer system to run the program with an automated tool to calculate the life cycle cost.

- Yes, if there is something better out there.
- Have a program that additionally tracks results to cover AFI or industry requirements. Like on a wet pipe fire system...log in static and residual pressures and inspector's test valve times. Or even backflow prevention device test results.
- System is acceptable but requires the deliberate review with cost and impacts considered. Getting buy-in from craftsmen is essential and pencil whipping to look good (100% RWP complete) has to stop.
- Yes, I think it needs to be changed; it needs an overhaul. Most RWP was created a long time ago, and it basically needs to be updated. Equipment is being built a lot better, and bases need to update their RWP registry needs to reflect the equipment they have today, not the equipment they had 20 years ago.
- I don’t think the program method needs to be changed, however there is a strong need for training the NCO and Civilian supervisors how to use the WIMS system, and the use of a AF 1841 which I haven’t seen used in 14 years. I don’t know how these techs go out and perform RWP without some kind of check sheet.
- Proper RWP can go a long way towards reducing energy costs and can also improve the safety/efficiency of the items being serviced. CE squadrons should make RWP a priority and ensure that all RWP is being done on time and by skilled/trained craftsmen.
- I really don't see much that should be changed. The best way to improve the program is to conduct frequent reviews of the program to make sure the right things are being serviced and that new items are added to the program. The shops should have inputs into the RWP program making sure that the right things are being serviced at the proper intervals.
- Frequent reviews of the program should result in items being added, deleted, number of hours allotted being adjusted, etc. There may be a way to "delegate" RWP for some items to the user/facility manager - but this could be a dangerous road to head down. That could be something you look at in your study though - are there items that the RWP could be "delegated" to the user/facility manager to take care of? It could potentially free up CE manpower to focus on other tasks.
- Yes it should be changed. Some tasks are very efficient (roof inspections, Heat plant RWP) However, some of the other RWWP actions are not accomplished properly due to

time, funds, etc (storm drains, ball fields, curb maintenance) Our AF RWP program is used for just about every piece of HVAC/R equipment, what is cost effective to complete and what is better to just allow it to "go-down" or break? Also, some units do not sit with their maintenance engineering Mechanical Engineers to actually complete required annual review, nor do most bases keep the equipment/listings up to date.

- It has been a little over four years since I've had daily involvement in the RWP so I'm sure things have changed somewhat since then. From my experience you main thing that needs to change is that we need to actually do the RWP rather than say we're doing it.
- Predictive vs preventive maintenance. There was a big push at one time when we started going under ACES; we were going a more predictive maintenance mode, but I'm not sure why we lost that. It's a common sense approach, but the computer doesn't allow us to do it. Instead of applying the same amount of hours to a brand new piece of equipment than we do to an old piece of equipment, we'd increase the inspection frequency as the equipment ages. We all know it takes more money and more manpower to maintain an old car that it does a new car, but they want you to change the oil every 3000 miles regardless. On the new side we're putting in too many hours; on the older side, we're not putting as many hours as we need to be. Also, even though there are several like pieces of equipment, its location and function may dictate the RWP being performed. We have the ability to depict this but don't always do. We need to take each piece of equipment, work it, and validate it every year.
- Making good decision about what to include in the program and what to run to failure, using industry standards to write MAS, and applying lessons learned. Updating our equipment inventories would allow us to make better conscious decisions about maintenance before the equipment fails. Whether we decide we want to do maintenance on equipment or not, we still needed to know if we own it. It still needs to be tracked even if the RWP frequency is zero.
- RWP needs to change if the AF wants to make it an effective program. We do not have the resources (manpower or funds) to perform complete preventive maintenance on every piece of equipment we are responsible for. Unfortunately, we also do not have the expertise or time for our engineers/foremen to devote much time in adjusting RWP as new equipment/facilities are added, age, or replaced. Ideally, RWP would concentrate on

items whose criticality and/or expected failure rate would dictate that it would be economical to spend resources on preventive maintenance versus allowing it run to failure and subsequently replacing it. Our bases RWP programs run the entire spectrum from having very few items at critical facilities only to having all items from all facilities in the program. There are many loopholes in the IWIMS RWP module to defer planned work so the system may not flag overdue items as effectively as it should. A new modern preventive maintenance management system will hopefully be included in the successor to IWIMS.

- The overall concept of the program works well, but I think it needs to be changed for the simple fact that manning is not what it used to be. With deployments like they are and cutting back on the workforce in an attempt to save manpower dollars, I think the processes need to be revised to cut down on the hours spent on certain types of maintenance. This could be done by doing better cost analysis on replacement value of the equipment.
- RWP should be changed to automate maintenance history on all facility subsystems. The technology is there to do this...and we need to invest in it. We should bar code facility subsystems and automate scheduling of inspections or replacement to pre-set times just before we think they are going to fail (based on industry stds, of course)...if "run to failure" is the asset management strategy for that subsystem. Of course, routine maintenance at the right time to preserve/extend system life as we've always done must be retained as applicable...but must be done with discipline. Funding, performance reporting, and awards programs should speak to and reward RWP compliance. Instead, we allow additional duties and "whole person" activities to overshadow bread & butter, make-the-trains-run-on-time recurring maintenance. We probably need beefed up training on the art/science of recurring maintenance....tech schools & AFIT...along with updates on state of the art from private organizations (e.g., IFMA).
- I would say more education and training because I have a problem with new people coming in convincing them exactly how RWP should work and the importance of it. I think more towards training exactly how RWP is supposed to be done and why. Sure RWP can be slimmed down in certain cases, but the whole picture has to be looked at. There may be pieces of equipment that are only worth so much money and they're easier

to replace, but you must look at the systems as a whole and not the individual components like RWP tends to do.

- Yes, there are items that can be deleted and more time could be spent on RWP items with more importance.
- I believe the current RWP should be changed to a system that is more user friendly for developing maintenance action sheets, adding/removing equipment items, and scheduling frequencies. I understand the desire to keep RWP in IWIMS for command access to information, but perhaps a commercial RWP program with downloadable reports available to interface with IWIMS could be implemented.
- We need to complete line by line review of the program at each base and decide what is important and what is not. We can use industry as a baseline. Sometimes it is better to let equipment fail and replace than doing RWP. It depends on equipment and what base it is on (Mission, environmental etc.)
- Change RWP? Yes. What can change? Educate CCs at all levels of RWP criticality, provide CCs the tools and flexibility to overcome manpower/resource shortfall and "stay ahead" of RWP backlog (contract); provide visibility of RWP effectiveness through asset mgmt tool sets.
- The stop gap solution to reinvigorate RWP is to discontinue use of the IWIMS RWP schedule program and only perform the necessary material and labor transactions against the appropriate Work Order. It is not necessary to build an RWP schedule in IWIMS it is only necessary to perform the cost accounting and the RWP record is not essential to meet that requirement; only the collection work order is needed. The management of RWP schedules should be done utilizing a simple manual schedule built in Excel or Word until a new software solution is provided.
- I wouldn't say RWP needs to be changed so much as it needs more attention and management. Unfortunately, this requires a great deal of time…a commodity less and less available these days. Instead of active management, we have a tendency to just go with the flow and execute a myriad of RWP actions without question whether it is all truly needed or not...or, we defer RWP actions to reapply man-hours to other things.

***Question 3: Have you experienced or witnessed any particularly effective RWP practices and/or procedures? Please explain.***

- Nothing truly outstanding.
- Not that I know of.
- My Operations Flight minimized the time allotted to RWP to only those items which would be cost beneficial to perform. RWP on a specialized or expensive piece of equipment was scheduled and performed, but RWP on low cost items was cut. For instance, monthly oiling of a ceiling fan (per the manufacturers recommendations) was cut because four monthly visits at a $32/hour shop rate was about equal to the cost with installation of a new fan. If the fan lasted more than four months of operation without RWP, it was cost efficient to run to failure. The time previously “wasted” on low value RWP was reinvested to actual maintenance on higher-value, more critical items, such as well-pumps, HVAC motors, lift stations, fire systems, etc. The results were only three emergency DSWs attributable to equipment failure in a one-year period. Remember, if the ceiling fan fails, it isn’t an emergency.
- I haven’t experienced an effective RWP program since the AF did away with AFR 85-2.
- We had a really good SMSgt who conducted frequent reviews of the RWP program to make sure the right things were being serviced at the right intervals. He would adjust the program whenever warranted based on new items coming on line or old items being decommissioned. He would analyze the number of hours shops were spending on certain items and in certain areas and would adjust the program accordingly to make the shops more efficient. One very effective program I saw was we created a dedicated "mech room maintenance" team. This team went around to every mech room on base. They cleaned, painted, serviced/fixed old items, etc. This was a short term program where they spent one or two days at every mech room on base until all were completed. A lot of the stuff they did was aesthetic - but they also did a lot of RWP while servicing each mech room. This was a short term effort to fix mech rooms - but the concept could apply in that a dedicated RWP team could be established to go around the base conducting all RWP that needs to occur. Similar to the DIN truck program. Another effective program was a facility inspection team that went to every facility on base over a certain period and walked through the entire facility looking for problems. While there, they would fix small things on the spot - change light bulbs, ceiling tiles, etc. If there were major

problems they would either call in a DSW or have the facility manager submit a 332. While inside the facilities, they would take care of some minor RWP as appropriate.

- The most effective practice is to have our civil, electrical and mechanical engineers sit and review the RWP program with the craftsman to determine which are the best and most cost effective tasks to complete. This saves dollars, man-hours and time.
- A way to gauge the program is to measure the effectiveness of creating a plan and sticking to it. Your assessment looks at the impact of sticking to your schedule and you must explain your ability to stick or not stick to the schedule. You will have competing priorities; if you're unable to stick to your plan, it's either a bad plan or your competing priorities are too much. There may be a correlation between a poorly executed plan and the number of emergency failures.
- When I arrived at one of my past assignments, RWP was wacked – we had more RWP hours scheduled than we had total hours available, so there was no way we could ever complete it all. We were forced to revamp the program whether we wanted to or not because it was unmanageable. We took top down review, dug into the maintenance action sheets (MAS) and performance work standards in IWIMS, and we started tweaking it; we asked tough questions, prioritized for facility use and mission, and applied risk avoidance vs risk acceptance. It took about three months to dissect the program piece by piece, but we ended up cutting the program almost 65% and never degraded our service. This was during QAF, so there were metrics for everything, and the numbers proved that we didn't change our service. In fact, we improved service because we now had more manpower available to respond to emergencies and other work priorities. We had EMCS there and we installed remote cameras and controls to dissect problems and take readings. These are ways to aid in doing RWP more effectively. You can also adjust temperatures, measure vibrations, make notifications, etc. from a remote location. This saves on a lot of manpower and extra effort, and its one way to do RWP better than we're doing.
- No.
- In manufacturing, we used Gauge Repeatability and Reproducibility (GRR) analysis methods to predict equipment variability and subsequent failure before the event occurs. A similar philosophy could be used for RWP such as a noisy HVAC motor bearing

would indicate unforeseen vibration which would then lead to suboptimal performance and may predict impending failure. This may be of value to highly critical equipment, but is too resource intensive for everyday use. Plus, very few if any CE engineers are knowledgeable in this area.

- Yes, the British were very meticulous about having up to date "asset registers" and performing RWP, with contractors employing a bar coding system. I have also had very good experience with shops that had an ownership interest in their systems and kept on top of not only their RWP, but their Long-Range Infrastructure Plans as well. Some of our own programs are very good...shops such as LFM, Power Pro, and Pest Management where they are not dogged with emergency/urgent work. Cross-talking lessons learned and best practices from them to the other shops should be encouraged.
- Emergency and urgent work will decrease with a good RWP program in place. This will cut down on numerous calls and trips to facilities if problems are detected early.
- Yes, I have witnessed shops that use their RWP based on the manning (due to deployments), and what facilities are mission critical. This is an effective way to make sure your man-power is allocated to the number 1 priorities.
- Yes. I have witnessed positive effects of RWP when the focus on the program was prioritizing time toward common failure items regardless of their cost (within reason), as well as our high dollar components/equipment. Since the beginning of the Air Force's personnel downsizing initiatives in the early 90's, I've heard more and more that base level CEs should concentrate efforts on high dollar equipment and just replace low dollar items as they break (failure maintenance). However, while I agree there is some items that just doesn't make sense to expend man-hours on rather than replace such as bathroom exhaust fan motors, it is not appropriate for all low dollar cost items where it is vital to the operation of a larger system. We (base level CEs) have limited amounts of O&M dollars and without effective RWP, sooner or later we will find ourselves having to purchase significant amounts of low dollar equipment items on a frequent basis, and we simply will not have the resources to do so.
- There are no certain practices that stick out.
- Effective practice #1 (rigid checklists and individual accountability): At a former assignment with the Navy, they established a rigid inspection list that drove individual

maintenance actions and accountability on a daily basis...simple B-hut and site maintenance...but it was daily/weekly routines and there was individual accountability (small team and each individual had his/her own inspection/repair checklist daily/weekly...didn't do anything else before we did this simple routines each day). Effective practice #2 (flexible service contracts to augment RWP): during heavy deployment cycles and when we were backlogged, we hired a local HVAC contractor to partner with couple of airmen ...the airmen paired with professional mechanics...effectively these airmen were "leading" a small team and learning as they systematically plowed through mechanical rooms...greasing bearings, changing belts, cleaning coils and adjusting/checking controls...didn't solve all problems but it brought back confidence that the shops had other tools to keep themselves on the RWP track! Effective practice #3 (SMART teams for routine/cycle inspections and limited maintenance): we had a SMART team (small scale maintenance and repair team). This team would go through major buildings (high occupancy or community facilities) every 3-6 mo and would knock out job orders and obvious/minor maintenance/repairs (lights/switches/plumbing)...in addition they provided "whole facility" inspections, providing feedback to maintenance engineers and shop chiefs on overall condition and provided recommendations on structural, roof, mechanical, electrical and plumbing systems.

- I have seen a trend in Power Production shops to create local RWP schedules using excel spreadsheets due to the inflexibility of the IWIMS program. Here in PACAF we still have some heat plants and to improve the RWP (PMI) of the plants a contractor was hired to customize their proprietary PMI management software to better manage the plant PMI program.
- No. I have not experienced any particularly effective programs.
- Nothing in particular. Some bases manage the program better than others...just a matter of where the focus happens to be at the moment.

***Question 4: What are the biggest threats to the success of RWP?***

- Reduced manpower, reduced funding and lack of program review.

- #1 would be lack of IWIMS training, and then lack of understanding the program, human error, charging time and closing items without actually doing the work (pencil whipping)
- Building too big a program then pencil whipping to meet metrics but not doing the work…aka pencil whipping…many shops do it. Compare emergency DSWs and RWP completion--if both are high, try explaining why someplace that has completed all RWP can have many emergencies for equipment failures. As an example, typically bases that are actually cycling switch gear and calibrating breakers will have fewer electrical outages.
- I think the lack of interest by Officer and Civilian Managers at the higher levels to continue pressing the importance of RWP.
- The biggest threats to the program are bases not taking it seriously and not dedicating the time and manpower needed to make it successful. This can be a big threat in that there are so many demands for CE time and manpower. Education needs to occur to base leadership to let them know how important RWP is and that the shops can't be constantly working wing CC interest items at the expense of the RWP program. Ops Chiefs and BCEs should be educated on the program to make sure they know the importance of it and to make sure that they are very strong advocates for the program.
- The biggest threat to RWP success is craftsman “buy-in”. A program can look great on paper; however the training, time and funds will be the biggest threat. Technology is advancing quicker than what we (AF) are providing or spending money to advance the knowledge of our personnel. Seems we believe when you learn HVAC you should always know it, but as we move deeper into electronics we are moving further and further away from the knowledge base of our personnel.
- The perceived lack of time and people to implement the program. Also the program is kind of "out-of-sight-out-of-mind" for the Wing CC. The BCE needs to convince the Wing leadership that RWP is important and time must be allotted to allow aggressive implementation of the program.
- In order to get some kind of assessment of the impact of your recurring plans, you need to have some method of assessing downtime, failures, etc, and those are extremely difficult to measure.

- We are taking a risk in infrastructure.  Our deployment rates are also leaving less time at home station to complete garrison work. So by default, CE has been forced to change from a proactive approach to a reactive approach to maintenance.
- Accuracy of records and time keeping is critical in order to compare the cost of maintaining equipment to the cost of replacing it (life cycle cost analysis).  Otherwise, you have no accurate data (proof) to go to your boss and show that you need to replace something.  You can’t do this if you’re not recording the facts.
- Annual reviews – there is a spot in aces that says we need to re-approve every year.  Part of that is having RWP signed off by the fire prevention office.  If we have a fire in a facility and find out it was due to poor maintenance, and we find out that the RWP wasn’t updated each year – there will be trouble.  If you dust off a MAS sheet and take a look at it, sometimes the equipment doesn’t even exist anymore.
- With the risk we’re taking in infrastructure, we need to have labor available to respond to emergencies.  Don’t chase the metrics, just state the truth.  You have a certain amount of work to do, and you only have a certain number of manhours available.  If you keep reporting RWP as good; you’ll look good for a while, but it will come back to bite you. They will continue to cut manpower until you hurt.  The cost is too high.
- Inertia (we've always done it his way), ownership (it's not my job to analyze it, it's the engineers in CEP's job), accountability (I'm not going to take that equipment off RWP, if it breaks I'll be blamed), knowledge (I don't know if this is critical enough to be added to RWP), and time (I'm undermanned and I don't have the time to devote to make RWP better).
- Lack of command emphasis...reviewing, validating, scheduling, and tracking execution....and tie to Long-Range Infrastructure Planning.  Allowing low availability rates on IWP...allowing absences and non-productive work to creep into the picture.
- The biggest threat to the program is pencil-whipping and having a program that everybody thinks is being maintained but in actuality is not.  Guys are going out and marking off hours to RWP, but when you actually go look at the work they’re not doing it.  There’s no integrity.
- Lack of knowledge Air Force wide on how the system operates works is one of the biggest threats.  The system has to be used not based on how many facilities or

equipment you have but on the man-power available to provide the maintenance to those items. In the past you simply added items and we had enough personnel to perform RWP now we have to adjust the system to allow management to effectively use personnel. There are not many people familiar with the system and how it works.

- The biggest threat to RWP is available manpower.
- Manpower cuts are the biggest threat to RWP. The loss of manpower due deployments result in RWP being cut and only focusing on Emergencies.
- Threat 1: Largely military RWP workforce (w/ competing deployment demands). Threat 2: lack of commander focus on recurring maintenance (WG CC on down).
- The single biggest threat to RWP is over emphasis on fixing things that have already broken rather than the preservation of existing assets. Furthermore, the difficulty of managing RWP in with IWIMS leads many shops to put little to no effort into maintaining their program due to the level of effort required.
- The biggest threat to the RWP program is the owners not utilizing it.
- The biggest threat to RWP has always been time: time for the program managers to administrate it, time for engineers and craftsmen to review and establish the best maintenance action sheets, and time for the shops to complete all necessary RWP actions.

***Question 5: Please add any additional thoughts, concerns, ideas, criticism, praise, or questions about RWP.***

- There is still a lot of lack of communication between shop and engineers that hamper the program.
- RWP is worthwhile program if it is managed right - if you have the right management in your organization that will let you show it the way it is instead of worrying about metrics, lets equipment break, and shows that we need more money or more people to maintain the equipment. Don’t worry about the metrics, worry about the equipment and customer service.
- I spent 9 years in the Maritime industry as a technician and a licensed Marine Engineer, In a Ship board operations you can’t afford not to do RWP otherwise you might find yourself out in the middle of the ocean stranded of worse someone could be hurt or killed for lack of preventive maintenance. My concern is the lack of many of our Military to be

able to perform and understand their core task and understand the benefits of RWP/predictive maintenance. Most Staff and Tech SGTs want a desk job as soon as they make rank and still lack the skills and knowledge to be proficient at their job. I also feel today's Senior NCO leadership fails to make the ranks accountable at the shop levels. Another issue is it's getting harder to find qualified civilian mechanics, young people coming out of schools today have no desire to get their hands dirty.

- My personal opinion is that it only makes sense to keep RWP in Ops in spite of the break-up of Maintenance Engineering. Considering the minimal staffing in CEP, and how thin the engineers are spread, they don't have time to manage this program effectively. No amount of coordination between CEP and CEO, which is problematic regardless of the issue, will be able to off-set the vastly different perspectives and objectives of each of these flights.
- There has been rumors for years about IWIMS going away and transitioning to ACES-Ops or some other new program. CE leadership needs to ensure that if a new program is chosen that it has the same capability as IWIMS to track and manage the RWP program. CE enlisted troops should be taught at the lowest levels (i.e. tech school) about the importance of RWP to ensure that they see the importance of the program and to ensure they "buy in" to the program. If they do not "buy in" to the program there is a chance they may blow it off and/or pencil whip the records and not take the program seriously.
- RWP is vital to keeping our infrastructure available to meet mission requirements. Make time to do it or you will pay the consequences in unscheduled downtime.
- It's great to have a work list, but you never have enough money or manpower to get everything done on that list. How you select from that list and determine what you will get done is the key to success.
- In order to account for commander's prerogative and unexpected events, your schedule must be flexible. The best way to ensure you stick to your schedule is adding a little wiggle room to account for these requirements.
- RWP is also a credibility issue for CE. Take for instance a facility that constantly has AC problems. When craftsmen are called there 4-5 days in a row to reset a chiller, what does the customer see? They see a craftsman who is not doing the job right the first time. We may be doing everything right, but we're losing credibility in our customer's eyes. With

an effective preventive or predictive maintenance program, you can identify problem equipment and schedule it for replacement.  CE can do anything, just can't do everything. Can we keep something running? Yes.  Should we keep something running?  If not, then go to leadership and get money to replace it.

- If I were king for a day, I would stop the lip service about RWP from a commander's perspective.  Stop telling me RWP is important if it's not on your priority list.  Let's call it what it is.  If it's not important, ok, but we will take risk in that and we won't put man-hours towards it; we just won't do it anymore.  Tell customers if it breaks it breaks because we're not coming to fix it.  But don't tell me RWP is important and give me all this other stuff to do like painting lawns and planting flowers for change of command ceremonies.  Stop giving lip service, and no kidding define priorities.  If RWP is at the top of the list, then staff me, fund me, give me the time to really do it, give me the materials, and hold me accountable for getting it done.  There has to be a balance, and we need to make RWP relative to our mission.
- With the short manpower and limited resources, there are huge potential savings to be had through RWP.  With all the 35 CE transformation initiatives, higher priority for RWP is something that has to be stressed; we're asking ops to do more with less.  You can't apply a cookie cutter approach to RWP because requirements aren't the same for every type of equipment.
- With the CE squadron transformation removing maintenance engineering from the Ops Flights, RWP has a reduced chance for success compared to years ago (and it wasn't that great years ago either).  We are losing ground in RWP as new facilities receive increasingly complex systems, the ops tempo reduces shop labor availability, and our craftsmen haven't kept up with changes in the maintenance industry.  Already we see our critical facilities in our command being maintained by contractors for $M each year instead of blue-suiters and I don't see this trend being reversed.
- I think the biggest issues we face are the manning shortfalls, and I see that a lot of things that are failing due to the fact that RWP is not getting done.  Especially now with the big concern for energy dollars, I think we should probably scale back on some of our maintenance to save on man-hours and consolidate our tasks to the ones that are the most significant and have direct impacts on energy costs.

- I've heard it asserted that some analysis has indicated that our RWP efforts have made no difference in terms of extending system life or preventing failures. I find that hard to believe, but if it's out there, it ought to be thoroughly examined and cross-fed across the career field. One area I've been burned on many times over is interdisciplinary RWP requirements...specifically hangar fire detection/suppression systems. In those cases, we have utilities, power pro, electrical/alarms, and fire department operating & maintaining parts of the system. When not coordinated properly, this can lead to system failures...burned up pumps/motors, foam dumps, etc. In cases like these, we should designate lead shops to closely coordinate all RWP. Other cases that come to mind are drainage systems containing gate valves (utilities & pavements/equipment players).
- I can’t emphasize the success stories of RWP enough, like Power pro when they do their generators – that’s a big success story, because that’s what they do and that’s their main job. Fire alarm systems are another example that has been particularly effective at my base because the fire department takes it upon themselves to get involved. Where I’ve seen it fail is in utility shops, for example where they’re supposed to clean out manholes. They don’t see the importance of it, but long-term if they could learn to understand the importance, they could cut down on the job orders and they’d see the savings in man-hours.
- The last thing, so many times we’ve had directors come down and say your priorities in Operations are #1) RWP, #2) DSW, #3) job orders. That philosophy is close, but it doesn’t work. Your #1 priority is emergency and urgent work; RWP would fall underneath that. Anyone who tells you RWP is their #1 priority is not telling the truth, because you’re going to respond to someone’s outage or damage before you go do your RWP.
- Many things can contribute to the success of a RWP Program. Available man hours as well as funding come immediately to mind. Another area to set you up for failure would be the lack of training on equipment and the vast number of different types of equipment. It is nearly impossible to train everyone on so many types of equipment. Also, if there was a standard, bulk purchases might save funding when ordering equipment such as HVAC equipment.

- It would be nice to have a training class on Operations element to assist in aligning all bases concerning RWP, Work Orders etc. Asset Mgmt and facility condition checks/assessments on routine basis may help refocus CE on pro-active maintenance (if they are implemented and focused at the bases). Currently the RWP process is generally only as good as the shop chief and there is little accountability. The more standardized objective view of RWP success/failures promised by asset mgmt tools and real property condition codes may increase accountability. Finally, providing ops chiefs the tools and the ability to avoid or dig themselves out of a backlog situation using "surge" service contracts (HVAC mechanics, for example) will further empower, and give shops chiefs confidence that they don't have to simply work harder to stay ahead of the RWP wave during repetitive deployments.
- More emphasis needs to be placed on establishing and managing cost effective PMI programs. Some ideas on how to do that are: 1. Increase the Urgent and Routine timelines from 5 duty days and 30 days respectively to 15 duty days and 90 days from the date of receipt of materials. The original standards where created during a period that the Air Force had excessive manpower and focused on garrison sustainment activities. Align the annual CE award criteria to those standards. 2. Immediately discontinue use of the IWIMS RWP program and provide options on establishing locally developed manual schedules until a new software solution is provided. The only necessary IWIMS operation is the cost accounting of labor and materials against a collection work order. This type of policy should be accompanied with guidance on management with roles and responsibilities defined for each element of CE. 3. Again, solidify the importance of RWP by creating or modifying the annual CE awards program to include more emphasis on RWP metrics.
- If I knew the program better, maybe I would find more uses for it.
- Somehow we need to streamline RWP. The process must actively determine what equipment and systems truly require periodic maintenance and what specific actions are needed at what frequency without going overboard. I would bet most bases' programs are too big and essentially have a mind of their own. They likely receive little management attention and shops are either spending too much time trying to maintain high RWP completion rates at the expense of more worthwhile work or they are allowing the

completion rates to slip by deferring the RWP to do other things (not to mention most craftsmen aren't thrilled with spending a lot of time doing RWP versus other Repair work). Maybe there's even some pencil-whipping going on. Overall, I suspect most installation programs probably need to get smaller...less RWP actions and at lower frequencies.

**<u>Section 2: Follow-up Questions (asked to individuals based on previous responses)</u>**

***You mentioned your current role in evaluating RWP programs across different bases -- do you see a wide variety of programs in terms of size or quality? Please explain.***

- Size and quality of the program very much depends on the personality in charge and the size of the labor force. If the emphasis from the top is on PM, then the program is generally good as well. If the work force is too small, RWP goes to the bottom because there are more urgent/emergency request that have to take priority over the routine. What I fail to see on a routine basis is a meaningful review of the program.

***You mentioned a lack of communication between shops and engineers -- why do you think this is the case?***

- There is still a blue collar versus white color conflict, experienced craftsman versus newly graduated engineer scenarios that hamper development of the program.

***How did you select your Chiefs of Maintenance Engineering? What level of importance did you place on this position relative to other CGO positions?***

- I place a lot of emphasis on that. I'm an industrial engineer by bachelors so I look at things from a different approach than a lot of other people, and I always found the maintenance engineering branch to have those types of looks. Having run Maintenance Engineering I considered it very important, and as an Ops Chief they worked for me. I had numerous opportunities to bring in new CGO's, so I looked for my strong people; I didn't consider maintenance engineering as a dumping ground for weaker folks.
- This was a balancing act between needs of all the CGOs to broaden their experience and the needs of the position. I once replaced a Capt with a 2Lt (after discussion and with concurrence of the Sq/CC) because it was best for CEO. As Sq/CC, I've also moved

CGOs (upon discussion with my CEO) over to CEO with the express intent on them becoming the CEOE, for career growth and not to solve the RWP problems. I've always thought CEOE was important in the squadron and wanted to move CGOs in there after they'd seen Engineering and probably Readiness, which tends toward the new or mid-time Capt. However, as from above, I've placed good producing LTs in there when the timing was right. Starting an accession in Ops as an Element Chief doesn't leave many opportunities to move them into Programs where so many civilians and few opportunities to continue leading.

***Did Maintenance Engineering play an active role in overseeing/evaluating the RWP, did the shops take primary responsibility for all RWP roles, or was it a mixture of the two?***

- Both. CEOE owned the bookkeeping (time) and shops owned the requirement.

***What would you change about the next generation of IWIMS with respect to RWP?***

- If I could make changes, the system would identify when scheduled maintenance is required and generate a request to the system; like some cars send a message when they need an oil change; piece of equipment would notify the shops – we're coming up on a 1000 hours, and you're required to maintain this equipment at 1200 hours…then people would go out and maintain the system based on the notification. A system within the equipment that interfaces with the work order management system.

***From your experiences at different bases, do you have any comments about how MAS sheets were used in the RWP?***

- With the MAS sheets, whether they are updated or not is based on the management – the ops chiefs and superintendents. That determines whether the MAS sheets are updated and whether the shop is doing the work according to the MAS sheets, and I've seen both.

***As far as annual reviews talked about in AFIs, have you seen the reviews take place?***

- No. I can think of 1 or 2 of sections that have gone through the annual requirement and updated/deleted MAS and RWP records. I've seen them done, but probably the majority wasn't.

***You mentioned you've witnessed a tendency for folks to pencil-whip RWP requirements - can you comment on this?***

- Yes, this also goes back to the management and shop chiefs; you need to let the equipment break. If you don't have the manning, the records need to show that. If you're pencil whipping data, you're showing that you can do the required RWP with the people you have and giving a false representation of what you can do. You need to let equipment break in order to develop a true picture of the equipment and RWP.

***Have you witnessed any effective measures to encourage the interaction between maintenance engineering and the shops?***

- If there is encouragement it normally is done by the Mechanical Engineer in Maintenance Engineering. At one base there was a very aggressive Mechanical Engineer who was very meticulous on RWP. He conducted and documented his annual reviews with each section...that was by far one of the best run programs I had been involved with. Most others are not as intense, but only an avenue to charge/account for time.

***Have you witnessed any barriers preventing the interaction between maintenance engineering and the shops?***

- The barriers would be time to accomplish. As we draw down in personnel, we have put a lot of responsibility on a small number of personnel. Now we are asking them to do more with less, and taking time out of their day to complete this is one of the last things they want to do. Most personnel are at their max work-load. Second would be the time accounting aspect of it. Most Ops personnel believe if you cut down the RWP you will be painting a picture to remove personnel. There is a relation, but not a direct relation to authorized personnel and # of RWP hours. That is a big misconception AF wide (it seems to me). CE UMD's are not matched to RWP like that.

***You mentioned lack of management attention as a weakness of the program; can you provide additional comment on that point?***

- RWP only becomes an issue for senior leaders when there are obvious problems. We often only think about problems when they're measured. In the case of RWP, it gets

pencil whipped and there is no real assessment into how accurate those check marks really are. Questions don't start getting asked until Building X starts having major recurring problems and it gets elevated to the squadron commander. Do I think commanders gave RWP enough attention? No. Is there a good way to see that it wasn't? That's what they pay their Ops Chiefs for. The types of things that an Ops Chief has to deal with are probably a good sign of how much focus is placed on RWP.

***Have you seen any best practices in industry that we could apply to the RWP?***

- The AF is starting to look at things in enterprise fashion, and it's long overdue. Why Base X buys carrier units and Base Y buys Traine has never made sense to me. We need to be more standardized across the AF and that would help us to do a better job with training, better job with maintaining equipment, etc. When you look at the corporate world, they do those sorts of things. I think we would do a much better job at picking the correct frequencies and knowing our trouble points and the things we need to work on if we had a centralized look at our assets. I think they also watch lifecycle data much better than we do.

***You mentioned that you used manufacturer's guidance as the primary source for developing MAS, when you've done reviews, have you strayed very far from the manufacturer's guidance?***

- No, not really. Most manufacturers recommend the same amount of maintenance for common equipment items.

***You mentioned the benefit of the automated system (IWIMS) – what are your thoughts about IWIMS with respect to RWP?***

- I think it works well with the RWP. IWIMS as a whole might need to be updated and brought into the next century, but with regards to the RWP I think IWIMS works pretty well.

***Maintenance Engineering was established in order to get degreed engineers involved with the shops and programs within Operations Flight, RWP being one of those program – has Maintenance Engineering been effectively used in this role?***

- This interaction does happen, but more often than not the person in maintenance engineering is someone who is not too experienced and they tend to just take the word of the craftsman. It depends if you have a shop chief who stays involved in the process – if they have 20-30 years experience it works well. But if you're talking someone who only has 10 years of experience and is tasked to go in and revamp the RWP list, I think those engineers might want to question their word. My experience is that when RWP tasks are changed, nobody in maintenance engineering will question it.
- No. They tried, but my experience with maintenance engineering is that they'd go out to the shops to evaluate the program, but they were asking the wrong questions because they didn't understand RWP because they'd never worked it. They were supposed to be evaluating RWP, but they'd come back more educated about it – they basically took the craftsmen's word, and say they were doing good.
- Maintenance engineering as a plan was a great one; I don't think we did it justice with the way we manned them and what we tasked them to do. I don't think we got their worth out of them. I didn't see maintenance engineers involved, but maintenance engineering wasn't staffed to the level to be able to apply engineering technical expertise to the craftsman expertise to really stand it up well. I'm sure there were placed that did, but in my experience there weren't.
- We mucked this up bad. The whole concept of engineers working with the shops, helping run through approvals (i.e. through fire department to make sure we're not busting any codes), re-evaluating MAS every year, etc is spot-on. The craftsmen need the expertise of the engineers, but the engineers need craftsman expertise too – they need the practical knowledge of turning wrenches vs statistical calculations. They're there to help improve on efficiencies, but we're not using them effectively. We don't put time toward it because it's not a priority. We need our degreed engineers to do engineer work. Not just programming.
- It has not been common practice for the interaction/annual review to occur in detail, as it should be. This can be a little time consuming, depending on what new equipment has been installed/replaced on base. If records are kept, or as new facilities come on-line reviews take place, then it wouldn't be difficult at all to accomplish. As you know, the RWP program in managed by Maintenance Engineering section...so they hold that

responsibility, however it also takes superintendents, shop foreman and craftsman to ensure this is accomplished. MAS (maintenance Action Sheets) have to be validated every year in IWIMS. Shop foreman, superintendents and Fire Dept have to sign off on it. I'd estimate that probably only 50% of the bases have this accomplished.

***What have you seen utilized as the primary source for developing MAS?***

- Start with manufacturers recommendation, filtered through warrantee and craftsmen's experience, then multiply by potential impact on mission resulting from failure and finally divide by cost
- To develop the MAS you start with the manufacturer's recommendation but as the equipment ages you factor in the maintenance history as well when you do your review.
- It should be a combination of manufacturer's recommendations, craftsman experience, and engineer's recommendations. For the more complicated and expensive items it should lean more towards manufacturer's recommendations and/or the engineer's recommendations (i.e. mechanical engineer in Maintenance Engineering). For the small, cheaper, less complicated items the craftsman should be given more say based on their expertise/knowledge/experience.
- Unfortunately I've seen too many wild guesses. I think you should use the manufacturer's recommended schedule coupled with mission requirements. If the part supports a highly critical mission and is the single point of failure you had better maintain it regardless of cost or time requirements.
- From my experience, the shops have seemed to just apply their own take on it. We have standards, but shops take the MAS sheets and adjust them according to their own knowledge and experience. Whether that is good or bad is somewhat immaterial, it's what is in their best judgment that we're doing.
- Manufacturer's specs are a starting point, but then it would have to be analyzed by craftsmen and engineers for total life-cycle costs. Then a RWP program can be developed based on available manning at that location. Finally, a feedback system would have to be in place to account for equipment additions, deletions, aging, mission changes, and other factors.

***You mentioned overseeing annual RWP reviews and other efforts to streamline the program; did you do anything particular or was there anything unique to your units that made sure these happened and were successful?***

- Nothing cosmic on the annual RWP reviews....really just a matter of me forcing folks to do it, and appointing my Chief of Maintenance Engineering to be the belly button. With Maintenance Engineering going away, I'd tag the Chief of the Ops Support element to be the OPR to coordinate the effort....probably with some oversight by the Ops CMSgt (assuming he's in the Ops Flt) and/or the Deputy Ops Chief. Regarding streamlining and simplifying the RWP...that's good, but you need to guard against the shops taking too much out. There's a tendency to do that to alleviate their workload...so it bears watching.

***If Maintenance Engineering was not performing the annual reviews, were the shops getting them done?***

- Here again it depends on the person, but I'd say ~80% of the time the shop is more capable of reviewing their systems because they know how they're supposed to work. This is where improved training could be useful, to teach folks why the system is there, how it's supposed to work, and how to evaluate it. I think 80% of the RWP can be evaluated by the shops themselves.

***You suggested extending the time requirements for urgent and routines; is this to de-emphasize their priority to allow RWP to get more attention? You're the first person I've ever heard mention this idea...can you explain it a little more?***

- Yes sir. We currently place to much emphasis on reactive breakdown maintenance and not enough on preventive maintenance. This problem is compounded by the difficulties of using IWIMS, the current OPS Tempo, and reduced manpower. Craftsmen become so absorbed in accomplishing job(work) orders by the AFI driven suspense that they will skip or pencil whip the RWP to accomplish the breakdown maintenance which results in more manpower to keep up with the additional breakdown maintenance due to poor preventive maintenance. This cycle continues until you have RWP programs that are unmanageable as breakdown maintenance, preventive maintenance, and funding requirements exceed available resources.

***You mentioned the EPS book as a reference for building MAS – can you provide some information on that?***

- It's a feature in IWIMS it's the time estimates required to perform subtasks on equipment or maintenance. I can't really send it to you as it's hard coded into IWIMS.

***If you were designing the replacement for IWIMS, what would be the 5-10 most important things to include in the design?***

- 1. The system would take into account all manpower requirements, available manpower(taking into account schedule leave, training, deployments), and suspense's then automatically spit out a recommended daily job assignment list for the shop which supervisors would use to assign daily job assignments. 2. The system would be portable, meaning craftsmen could carry a PDA to document, maintenance performed, hours worked, and overall condition of the system. 3. The system would allow craftsmen to research and order materials while at the jobsite. 4. The system would allow craftsmen to close, carry over, or defer the requirement at the jobsite. 5. The system would tell the craftsmen prior to going to the jobsite what materials to pickup prior to going to the jobsite. This would ideally to be the degree that the system would have identified 3-4 weeks in advance possible material shortfalls that would hinder the completion of the work. It would also present them with comments/findings made during the last occurrence of PMI/RWP. 6. The system would use historical data to automatically recommend the most cost effective level of PMI for each specific piece of equipment and recommend modifications to existing PMI tasks based on any previous breakdown maintenance activities.

**APPENDIX C.  RWP Review Guide and Decision Tool Concept**

This RWP review guide is intended only to provide a suggested method for conducting a RWP review.  It is not meant to be an official standard for reviewing an RWP, but it could be used as a foundation for developing such guidance.  This guide has two parts – the first part provides a methodology for reviewing a complete program; the section part provides a process for analyzing the RWP candidacy of new equipment that was not evaluated during the full program review.  The guide incorporates a framework for making decisions about how to decide which equipment to include in a RWP based on risk and available resources.  Due to inherent differences in the nature of work performed and equipment types utilized across different crafts, this guide should be utilized at the shop level.  Additionally, each shop manages its own set of personnel and is responsible for developing its own priorities and schedules.

Full Program Review Guide

The process outline in the following full program review guide should be performed at least once per year, but more often if organizational leadership deems it necessary.  Potential reasons for more-frequent reviews include (1) a considerable drop in available manpower or (2) a noticeable drop in program effectiveness.

1) Determine the approximate weekly man-hours available for RWP
   - Identify the number of personnel in the shop
   - Identify the approximate percentage of man-hours to allocate to RWP
   - Assuming a standard 40-hour work week, the available weekly man-hours for RWP is calculated as follows:

| | | | | | | |
|---|---|---|---|---|---|---|
| Weekly Man-hours Available for RWP | = | Total # Available Shop Personnel | * | 40 | * | Percentage of Man-hours Allocated to RWP |

2) Update entire equipment inventory
   - Verify that each equipment item on the list still exists
   - Eliminate equipment that no longer exists
   - Add any new equipment
   - Collect all relevant identification information for each equipment item: serial number, facility/room number, date of installation, etc

3) Assess the risk classification of each equipment item
   - Consider all potentially relevant factors: mission impacts, life/safety, regulations, government property, etc (refer to Risk Classification Guide in Appendix E)
   - Update any new risk classifications or any that have changed

4) Asses the MAS for each equipment item
   - Evaluate the frequency and scope in comparison with the following sources:
     - Industry guidance and established standards
     - If available, common RWP standards (see Appendix F)
     - If available, information from new metrics that may suggest frequency changes (see Appendix G)
   - If necessary, make changes.

5) Calculate the cost effectiveness of performing the RWP action for each equipment item
   - Determine the following values:
     - Minimum estimated life (the estimated life of the equipment if no maintenance is performed)
     - Maximum estimated life (the estimated life of the equipment if optimal RWP is performed, or the estimated scheduled replacement frequency of the item)
     - Interest rate (7% government standard per OMB Circular A94, Chapter 8)
     - Cost to purchase and install the equipment (all labor and materials)
     - Labor rate (cost per man-hour of labor)
   - Determine the equivalent annual cost of the equipment while performing the RWP using the MAS assessed during Step 4; this will include the cost to purchase and install the equipment spread over the maximum estimated life

$$\text{EAC of RWP} = \text{Cost to Purchase \& Install} * (A/P, i\%, \text{max est. life}) + \text{Frequency of Maintenance Actions} * \text{Man-Hrs Per Maintenance Action} * \text{Labor Rate} + \text{Material Cost Per Maintenance Action}$$

   - Determine the equivalent annual cost allowing the equipment to run to failure; this will include the cost to purchase and install the equipment spread over the minimum estimate life

$$\text{EAC of Run to Failure} = \text{Cost to Purchase \& Install} * (A/P, i\%, \text{min est. life})$$

- Calculate the ratio comparing the equivalent annual costs; since EAC of RWP is in the denominator, a cost effectiveness ratio greater than 1 means that RWP is more cost effective than allowing the equipment to run to failure – conversely, a cost effectiveness ratio less than 1 means that allowing the equipment to run to failure it is more cost effective than RWP

$$\text{Cost Effectiveness Ratio} = \frac{\text{EAC of Run to Failure}}{\text{EAC of RWP}}$$

- To calculate the cost effectiveness ratio using Microsoft Excel©, use the following equation:

  =(-PMT(*'Interest Rate'*,*'Minimum Estimated Life'*,*'Cost to Purchase and Install'*))/(-PMT(*'Interest Rate'*,*'Maximum Estimated Life'*,*'Cost to Purchase and Install'*)+*'Frequency of Maintenance Action'**(*'Labor Rate'**'Man-hours per Maintenance Action'*+*'Material Cost Per Maintenance Action'*'))

- If available, 'Common RWP Standards' may provide a list of cost effectiveness factors or a list of min/max estimated life values for specific equipment type/size combinations

6) Rank order all items according to risk and cost effectiveness
   - First sort is performed according to risk classification (High, Medium, Low)
   - Second sort is performed according to cost effectiveness factor…such that the highest priority equipment item on the list will have a high risk classification and the greatest cost effectiveness factor of all the high risk equipment items

7) Size the program according to the available resources
   - Calculate an estimate of the weekly man-hour burden of RWP on each equipment item; multiply the number of annual occurrences by the estimated man-hours per action, then divide by 52, as shown below for the different frequencies

| Frequency | Equation |
|---|---|
| (Weekly) | = (52*'Man-hours Per Maintenance Action') / 52 |
| (Monthly) | = (12*'Man-hours Per Maintenance Action') / 52 |
| (Quarterly) | = (4*'Man-hours Per Maintenance Action') / 52 |
| (Semi-annual) | = (2*'Man-hours Per Maintenance Action') / 52 |
| (Annual) | = (1*'Man-hours Per Maintenance Action') / 52 |
| (Bi-annual) | = (0.5*'Man-hours Per Maintenance Action') / 52 |

- Calculate a consecutive running total of the weekly man-hour burdens, starting with the first priority item on the list and going down
- Stop when the running total matches or surpasses the number of weekly man-hours available for RWP (as identified in step 1)
- Any equipment prior to the cutoff is included in the program; any equipment past the cutoff is not included in the program

8) Adjust the reviewed program as necessary
    - To include more equipment items in the program, consider increasing the total amount of man-hours available for RWP or decreasing the frequency or estimated man-hours per maintenance action for equipment above the cutoff
    - If necessary, consider overriding the risk/cost effectiveness priorities
    - Repeat steps 1-7 as necessary

New Equipment RWP Candidacy Evaluation Guide

The following review should be performed on any new equipment item installed in-between annual reviews of the RWP. This review is not necessary for replacements of broken equipment in which the identical piece of equipment is being installed; however, if the size or type of equipment is being changed, this review should be performed.

1) Assess the risk classification for the equipment item
    - Consider all potentially relevant factors: mission impacts, life/safety, regulations, government property, etc (refer to Risk Classification Guide in Appendix E)
2) Determine the appropriate MAS for each equipment item
    - Base the frequency, actions, and estimates on the following sources:
        - Industry guidance and established standards
        - If available, common RWP standards (see Appendix F)
        - If available, information from new metrics that may suggest frequency changes (see Appendix G)
3) Calculate cost effectiveness

- See Step 5 in the 'Full Program Review Guide'

4) Determine RWP Candidacy
    - Refer to the prioritized RWP list developed during the annual review; locate equipment with similar a risk classification and cost effectiveness ratio
    - If similar equipment is included in the program, consider initiating RWP on the new equipment; if similar equipment is not included in the program, consider waiting for the next annual review before deciding whether or not to initiate RWP on the new equipment
5) Add new equipment to equipment inventory and re-evaluate during next annual review

<u>Future of this Review Guide</u>

This decision framework suggested in this review guide provides a systematic process for prioritizing and sizing an RWP based on risk and cost effectiveness. In its current form, the review is certainly doable, although it is somewhat cumbersome. Ideally, this guide would serve as the foundation for a review framework that could be built into the next generation of IWIMS. Such a program could be developed to automatically identify risk classifications based on the type of equipment, location, related missions, etc. Additionally, the program could automatically reference guidance for the ideal MAS, frequency, pre-established cost effectiveness ratios, and other necessary information for each equipment type/size. Based on the risk and cost effectiveness factor, the system could automatically prioritize and schedule all RWP actions; it could also be designed to track individual equipment history from which adjustments to frequency and MAS could be made.

## APPENDIX D.  RWP Education Guide Concept

The purpose of this education and training curriculum concept is to provide a basic idea of the types of RWP-related topics that different people associated with the program should understand. This guide is based on information gathered during the data collection and literature review portions of this thesis, and it is only intended to provide a recommendation for the development of a standard education curriculum for Civil Engineers.

<u>All Craftsmen</u>

- Basic concepts of preventive maintenance – how it works, why it is important, etc

<u>Senior Craftsmen</u>

- How to develop Maintenance Actions Sheets (MAS)
- How to identify problems with MAS and recommend/make changes
- How to create and balance a schedule, manually and with IWIMS (or its replacement)
- Importance of annual reviews and accurate data tracking

<u>Operations Controllers</u>

- How to properly monitor and assist with daily implementation of RWP
- How to facilitate a full RWP review and updates

<u>Shop Supervisors</u>

- How to conduct a full RWP review
- How to incorporate risk and system impacts into analysis of MAS
- How to utilize IWIMS (or its replacement) to optimize a schedule

<u>Maintenance Engineers and Company Grade Officers</u>

- Basic concepts of preventive maintenance – how it works, why it is important, etc
- How to develop Maintenance Actions Sheets (MAS)
- How to identify problems with MAS and recommend/make changes
- How to incorporate risk and system impacts into analysis of MAS
- How to conduct a full RWP review

<u>Operations Flight Chiefs</u>

- How to analyze a weekly schedule
- How to develop and use metrics to drive performance

<u>Base Civil Engineers</u>

- How to communicate the importance of RWP to MSG and WG leadership

## APPENDIX E. Risk Classification Guide

The purpose of this risk classification guide is to suggest a method for defining the risk classification for a given system or equipment item, and to provide some examples of equipment, systems, or facilities that meet each risk classification. For this thesis, risk is defined as the potential negative impacts of <u>not</u> performing RWP on a given equipment item or system. Knowing the risk classification of an equipment item or system can be very helpful when prioritizing the expenditure of limited maintenance resources.

<u>High Risk Category</u>

Equipment that meets the high risk classification should be the top priority for receiving limited maintenance resources. Failure of equipment with this classification could either (1) directly interrupt a critical mission, (2) cause unacceptable personal injury or loss of life, (3) lead to mission down-time for repairs that would interrupt critical missions, or (4) unacceptable damage to government property. Examples of equipment that meet each of the listed conditions are given below.

- Failure could directly interrupt a critical mission: a power generator at the control tower
- Failure could cause unacceptable personal injury or loss of life: a runway barrier system
- Failure could cause unacceptable damage to government property: an air conditioning system for a computer network server facility
- Failure could lead to mission down-time for repairs that could interrupt critical missions: an inoperable fuel pump on the flight line

<u>Medium Risk Category</u>

Equipment that meets the medium risk classification should be the second priority after high risk equipment for receiving limited maintenance resources. Failure of equipment with this classification could either (1) cause a potential safety hazard, (2) cause a code or regulatory violation, or (3) seriously affect other scheduled work. Examples of equipment that meet each of the listed conditions are given below.

- Failure could cause a potential safety hazard: an electrical transformer
- Failure could cause a code or regulatory violation: a fuel storage tank
- Failure could seriously affect other scheduled work: the HVAC system at wing HQ

<u>Low Risk Category</u>

Equipment that meets the low risk classification is the lowest priority for receiving limited maintenance resources. Failure of equipment with this classification may cause minor inconveniences or work-arounds, but will not significantly impact an overall mission. Examples of this type of equipment include traffic lights and bathroom exhaust fans, and actions such as street sweeping.

## APPENDIX F. Common RWP Standards Concept

The Common RWP Standards concept was discussed in FA #5; these common standards would consist of craft-specific Maintenance Action Sheet (MAS) templates and guidance developed in conjunction between AFSC functional experts, engineers, and operations support staff at a centralized organization (i.e. AFCESA). Common RWP standards across the Air Force would be a great way to reduce the time, effort, and guess work involved in creating and updating a RWP. Since RWP requirements for certain equipment will vary from base to base due to different mission requirements and environmental conditions, the common standards should not serve as strict requirements. Instead, these standards should provide a starting point for developing a program and a common basis for program review/evaluation.

This appendix is not intended to serve as an official standard for the Common RWP Standards; rather, it is intended to provide a foundation for developing future common standards. These examples fall into two categories: (1) Flight Standards Concepts that apply to the entire Operations Flight (regardless of craft) and (2) Craft Standards Concepts that apply to each craft or shop as a separate entity.

<u>Flight Standards Concepts</u>

- Flight standards should identify the most effective metrics to gauge the performance of RWP and provide instructions on the necessary data to collect and how to calculate the values
- Flight standards should identify common systems that require multi-craft RWP and provide a template from which to facilitate and streamline these efforts
- Flight standards should provide a common template for establishing and operating a facility maintenance tiger team, to include suggestions for team make-up, task lists, and objectives
- Flight standards should provide a common template for requesting, funding, and directing a ‘surge capability’ service contract to assist with large backlogs of overdue work, to include suggesting on when such a capability would be appropriate
- Flight standards should identify a common procedure for tracking equipment warranties, as well as decision guidance for sustaining warranties based on cost effectiveness
- Flight standards should emphasize the use of the Air Force Civil Engineer Operations Support Branch Community of Practice (CoP) to suggest/share tricks of the trade and changes to the official common standard guidance
- Flight standards should be periodically updated to ensure maximum relevance and utilization

Craft Standards Concepts

- Craft standards should identify all types of equipment/systems that the craft will maintain (example: HVAC maintains blowers, chillers, boilers…)
- For each type of equipment, craft standards should provide:
  - Recommended brands (for cost, quality, or maintainability reasons)
  - Maintenance Action Sheet (MAS) templates for various ranges of equipment size, to include:
    - Optimal frequency of actions
    - Labor and materials estimates
    - Bills of materials
  - Cost effectiveness rating – a value that compares the average initial cost to purchase and install versus the cost to perform the recommended MAS.
  - Risk classifications guidelines – identifies the common risk classifications for a given type of equipment depending on mission, location, hazards, regulations, etc
  - RWP impact rating – a value that compares the average lifespan of a properly maintained system to the lifespan of a system that receives no maintenance whatsoever
- Craft standards should identify manpower scheduling objectives and provide manpower allocation recommendations – these vary between crafts depending on the nature of the work they perform…some spend most of their time working on RWP while others spend very little of their time on RWP
- Craft standards should emphasize the use of AF-wide craft-specific CoPs to suggest/share predictive maintenance practices, remote sensor technologies, tricks of the trade, and changes to the official common standard guidance
- Craft standards should be periodically updated to ensure maximum relevance and utilization

## APPENDIX G. New RWP Metrics Concept

The current metrics for RWP do little more than demonstrate a shop's ability to charge labor to the program. Two new metrics that could possibly provide a better depiction of RWP performance are suggested below. These are not intended to serve as an official standard for new RWP metrics, but are intended to provide a foundation for developing future RWP metrics. These metrics can be produced using the current IWIMS; however, the potential capabilities of a replacement for IWIMS could enable new and more powerful metrics.

<u>Metric 1</u>

Metric: # RWP actions skipped or deferred compared to the total # RWP actions scheduled for a given period

Calculation: value would be represented as a percentage; example: "93% of all RWP actions for this month were completed as scheduled"

$$= \frac{(\text{total \# actions scheduled}) - [(\text{total \# actions skipped}) + (\text{total \# actions deferred})]}{(\text{total \# actions scheduled})} \times 100\%$$

Ideal Value: as close to 100% as possible

Possible Interpretations:

- High value w/ no effects on equipment performance: the shop has done a good job of developing their RWP actions based on available manpower, and has done a good job of scheduling to meet those actions
- High value w/ negative effects on equipment performance: the shop could be pencil-whipping completion to eliminate skipped or deferred actions
- Low value w/ no effects on equipment performance: the shop could possibly decrease the frequency of RWP actions to alleviate manpower for other requirements
- Low value w/ negative effects on equipment performance: the shop may not have enough manpower resources to complete all necessary RWP or the shop may need to revise and prioritize the program to minimize the impacts of the negative effects on mission

Benefit: demonstrates a shop's ability to develop a RWP and produce and execute a schedule; also serves as an indicator of when/where potential adjustments to the program could be made

Metric 2

Metric: date of the most recent program review compared with the current date

Calculation: value would be represented as a simple stop-light chart based on the number of days since last review; 0-270 Days = Green, 271-365 = Yellow, 365+ = Red; the ranges for the different colors could also change depending on commander's prerogative to align with AEF movements, mission changes, etc

$$= \text{(current date)} - \text{(date of last review)}$$

Ideal Value: green is ideal

Possible Interpretations:
- Green: no action required
- Yellow: it is time to prepare for and execute a program review
- Red: someone has failed to do their job

Benefit: serves as a simple reminder to keep annual reviews in the spotlight

## APPENDIX H. SWOT Analysis Summary Chart

| SWOT Finding | | Addressed By: |
|---|---|---|
| **S1** | The basic concept/intent of the program and the basic instructions (as outlined in the current references), if implemented properly, can produce a very cost effective and efficient maintenance program | FA1, FA2, FA3, FA4 |
| **W1** | Actual performance data for RWP actions is not being collected/recorded accurately | FA1, FA4, FA6 |
| **W2** | Annual reviews of the RWP are not being completed | FA2, FA3, FA5 |
| **W3** | Maintenance Actions Sheets are not being adequately developed and/or updated | FA3, FA4, FA5 |
| **W4** | The metrics used to gauge RWP are encouraging poor practices | FA8, FA4 |
| **W5** | Leadership attention to and accountability within the RWP are lacking | FA4, FA3 |
| **W6** | Education about how to implement a RWP and the benefits of an RWP are lacking | FA3, FA4 |
| **O1** | Develop a risk/cost-based decision framework to assist with reviewing the RWP | FA6, FA5 |
| **O2** | Capitalize on advances in computer-based maintenance management technology | FA6, FA8, FA7 |
| **O3** | Implement predictive (conditions-based) maintenance practices and technology | FA7, FA6 |
| **O4** | Establish and disseminate organization-wide standardized approaches to RWP | FA5, FA8, FA3 |
| **O5** | Establish and utilize communities of practice to share RWP information | FA3, FA5 |
| **O6** | Develop and utilize a service contract 'Surge Capability' | FA5, FA4 |
| **O7** | Encourage multi-craft coordination for RWP activities | FA4, FA5 |
| **O8** | Utilize RWP to sustain equipment warranties | FA5, FA3, FA6 |
| **T1** | The RWP is just one of many priorities competing for limited resources | FA3, FA6, FA8, FA4 |
| **T2** | The RWP has a poor image that may hinder improvements to the program | FA3, FA1, FA2, FA4 |
| **T3** | Craftsmen and engineers are functionally separated within the CE unit | FA4, FA3 |
| **T4** | New Operations Flight Chiefs have very little or no prior experience in operations | FA3 |
| **T5** | RWP is rarely adjusted to meet changes in available manpower | FA2, FA1 |
| **T6** | RWP is used incorrectly | FA3, FA5 |
| **T7** | RWP decisions do not always consider the whole system perspective | FA3, FA5 |
| **U1** | Utilize energy savings potential to measure and adjust the RWP | FA3, FA6 |
| **U2** | Delegate minor RWP tasks to facility managers | FA3, FA7 |
| **U3** | Extend completion suspense for urgent and routine Direct Scheduled Work | FA4, FA5 |

## APPENDIX I. Focus Area Summary Chart

| Category | Focus Area | | Description | Supporting SWOT Findings: |
|---|---|---|---|---|
| 1 | FA1 | Accurate Recordkeeping | Accurate records are necessary in order to track operational performance, resource utilization, equipment condition, etc. Failure to keep accurate records produces a false representation of an organization's capabilities and provides no basis from which to request additional resources or adjust priorities. | S1, W1, T2, T5 |
| | FA2 | Annual Reviews | Annual reviews are the opportunity to optimize and prioritize a program to get the best return for the resources invested. Equipment inventories must be updated, RWP actions/frequencies must be tailored to minimize waste and maximize benefit, and the overall program must be adjusted to match available resources. | S1, W2, T2, T5 |
| 2 | FA3 | Education and Training | Education and training are necessary to ensure the personnel involved with RWP understand the importance of the program and how to properly implement it. Education and training should be focused at all levels of the organization if order for the RWP to produce effective results. | S1, W2, W3, W5, W6, O4, O5, O8, T1, T2, T3, T4, T6, T7, U1, U2 |
| | FA4 | Leadership Attention | Leadership attention to the RWP is necessary to ensure the program receives the appropriate level of support and resources. Leaders must clearly establish the priority for the program in relation to other work and must hold personnel accountable for accurately tracking data and performing annual reviews. | S1, W1, W3, W4, W5, W6, O6, O7, T1, T2, T3, U3 |
| 3 | FA5 | Common RWP Standards | Common RWP standards across the Air Force are a great way to reduce the time, effort, and guess work involved in creating and updating an RWP. Common RWP standards should consist of craft-specific guidance to provide a starting point for developing a program and a common basis for program review/evaluation. | W2, W3, O1, O4, O5, O6, O7, O8, T6, T7, U3 |
| | FA6 | IWIMS Replacement | Computer-based maintenance management systems have improved exponentially since IWIMS was first introduced over 25 years ago. New technology exists to replace IWIMS with a drastically more effective tool that could positively influence all of the RWP Focus Areas. | W1, O1, O2, O3, O8, T1, U1 |
| | FA7 | Predictive Maintenance | Predictive maintenance, also known as conditions-based maintenance, uses routine inspections or remote sensing equipment to identify maintenance requirements. Since actions are only performed when needed, rather than according to a set schedule, predictive maintenance methods can help to conserve resources. | O2, O3, U2 |
| | FA8 | Redesigned Metrics | The current metrics for RWP focus on a shop's ability to charge labor to the program. New metrics should be created to gauge a shop's scheduling and program review procedures. Additional metrics could also be developed to gauge RWP effectiveness over system life-cycles and identify where changes are needed. | W4, O2, O4, T1 |

Category Descriptions:

1) Aspects of the current RWP which have been severely neglected; productive/effective RWPs focus heavily on these functions.

2) Aspects that are not official components of RWP but which are stressed in maintenance management literature; they help to ensure the appropriate tools and support for an effective RWP.

3) Concepts/ideas that take advantage of new technologies and best practices within the maintenance industry to make RWP more practical, less time-consuming, and/or more productive.

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## Vita

Captain Ross E. Dotzlaf originally hails from Greenwood, Indiana. After graduating from Center Grove High School, he entered the Service Academy Preparatory School at Marion Military Institute in Marion, Alabama on a Falcon Foundation Scholarship. After completing the program, he earned an appointment to the United States Air Force Academy, in Colorado Springs, Colorado. In 2004, he was a distinguished graduate of the Academy, having earned a Bachelor of Science Degree in Mechanical Engineering and an appointment as a 2nd Lieutenant in the United States Air Force. His first assignment was with the 3rd Civil Engineer Squadron at Elmendorf AFB in Anchorage, Alaska, and in August 2008 he entered the Graduate Engineering Management (GEM) program at the Air Force Institute of Technology. Captain Dotzlaf is married to the former Jennifer Wallisa of Indianapolis, Indiana, and has one daughter, Gwyneth.

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Properly implemented preventive maintenance (PM) strategies can provide many benefits to an organization in terms of extending equipment life, optimizing resource expenditures, and balancing work schedules. Periodic evaluation of a PM strategy can help identify ways to improve efficiencies and maximize its effectiveness. This research effort was accomplished by performing a case study of the United States Air Force's infrastructure and facility PM program known as the Recurring Work Program (RWP). Based on a thorough review of relevant maintenance management literature and data collected through a series of interviews, a strengths, weaknesses, opportunities, and threats (SWOT) analysis was performed to evaluate the current program. Findings from the SWOT analysis supported the formulation of eight Focus Areas (FAs), each which represents a unique theme of practical recommendations for improving the program. Using this research as a model, maintenance practitioners can formulate a practical framework to evaluate and modernize their PM strategy.

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